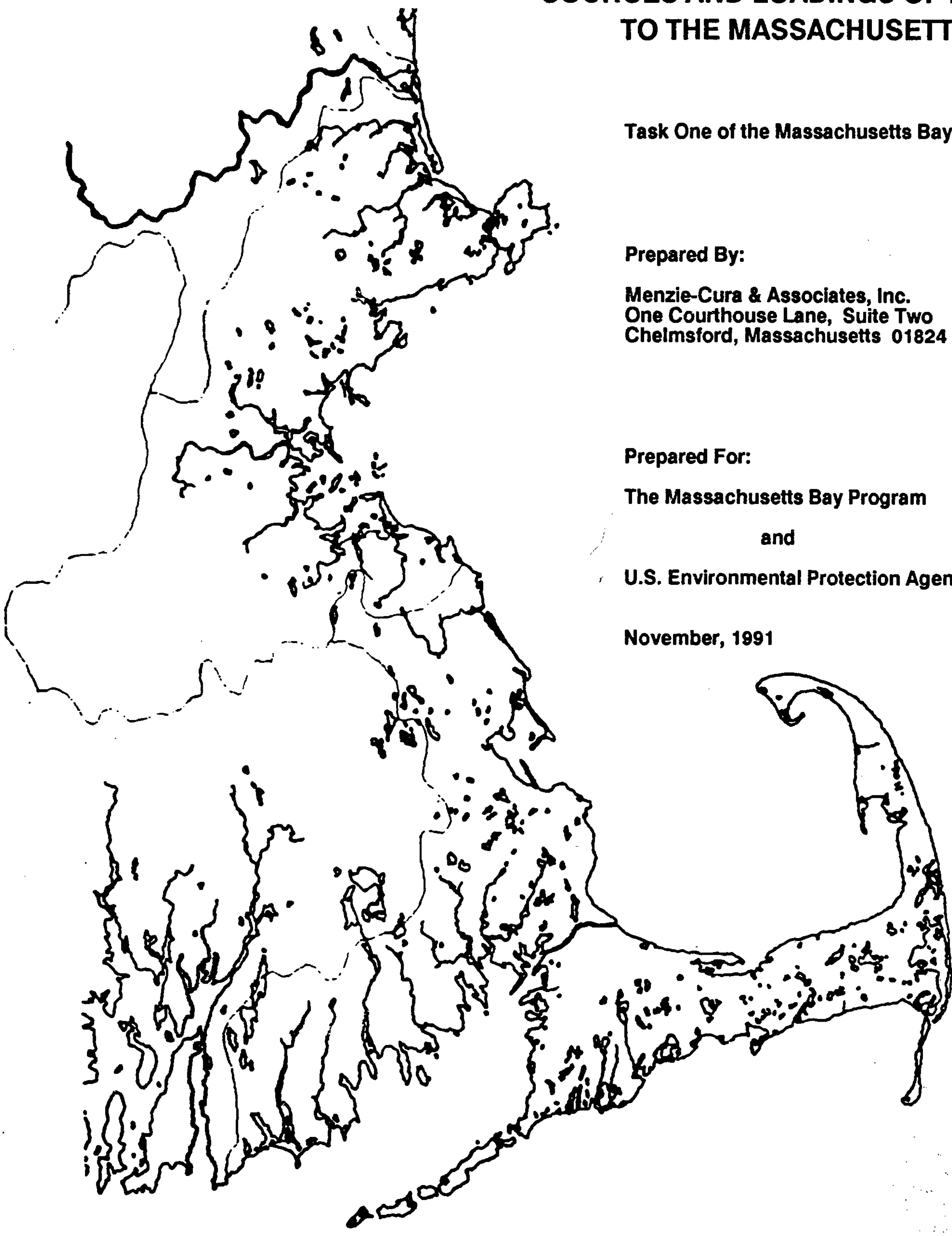
SOURCES AND LOADINGS OF POLLUTANTS TO THE MASSACHUSETTS BAYS



Task One of the Massachusetts Bays Program

Prepared By:

Menzie-Cura & Associates, Inc.
One Courthouse Lane, Suite Two
Chelmsford, Massachusetts 01824

Prepared For:

The Massachusetts Bay Program

and

U.S. Environmental Protection Agency

November, 1991

SOURCES AND LOADINGS OF POLLUTANTS TO THE MASSACHUSETTS BAYS

Task One of the Massachusetts Bays Program

Prepared By:

Menzie-Cura & Associates, Inc.
One Courthouse Lane, Suite Two
Chelmsford, Massachusetts 01824

Prepared For:

The Massachusetts Bay Program

and

U.S. Environmental Protection Agency

November, 1991

ACKNOWLEDGEMENTS

The primary authors of this document are Christine Werme and Charles A. Menzie. We were assisted by many people, some of whom authored specific sections of the report, and others of whom offered guidance or assistance.

Bonnie Potocki and Jerome Cura assisted us in preparation of the sections on inputs from point sources and from rivers. The section on loadings in groundwater was written by Jon Freshman. Brian Field prepared the sections on loading from dredged material and in-place sediments. The section on loading associated with atmospheric deposition was prepared by William Galen. Kay Reddy prepared the section on the spatial distribution of hazardous waste sites near the coast and rivers. General administrative support and production of the final document was coordinated by Joan Pioli.

Many of the data we used to estimate loadings from point sources were obtained from the U.S. Environmental Protection Agency Resource Information Center. Personnel at the center assisted us by retrieving data from their permit compliance system (PCS) database. Michael Connor and Wendy Smith of the Massachusetts Water Resources Authority (MWRA) provided us with additional information to develop our estimates of inputs from point sources. The MWRA also supported a separate effort to estimate loadings to Boston Harbor.

The estimates of loadings from runoff were made using data from the National Coastal Pollutant Discharge Inventory, which was developed and is maintained by the National Oceanic and Atmospheric Administration Ocean Assessment Division. Daniel Farrow of that office provided those data to us and assisted us in adapting the available information to our use. He also provided us with data on land use in the region and provided us with guidance for developing estimates of loads from point and nonpoint sources. Philip Shelly of EG&G also provided us with guidance for estimating inputs from point and nonpoint sources. He developed and reviewed our strategies prior to our preparation of this document.

Warren Kimball of the Massachusetts Division of Water Pollution Control provided us with data and documents to assess water flow in the region. He also assisted us in dividing the system into drainage systems. Gordan Wallace of the University of Massachusetts at Boston provided guidance for use of data for estimating loads from rivers.

Many of the data used to estimate loadings from atmospheric data were based upon regional estimates that were provided to us by Ilhan Olmez of the Massachusetts Institute of Technology.

We prepared this document under the direction of Diane Gould, Program Coordinator for the Massachusetts Bays Program, at the Massachusetts Executive Office of Environmental Affairs (EOEA). We thank Dr. Gould, as well as Judy Pederson and Jan Smith of EOEA, for their direction and support. We also thank Matthew Leibman, the Program Coordinator for the Massachusetts Bays Program at the U.S. Environmental Protection Agency, Region I, Water Management Division.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

This report identifies and quantifies sources and loading of pollutants to the Massachusetts Bays system. The report provides the results of Task 1 of the Massachusetts Bays Program (MBP). The MBP is developing a plan for conservation and management of the estuarine waters from the New Hampshire border to the tip of Cape Cod.

The general approach of this study was to identify important pollutants to the Massachusetts Bays system and, to the extent possible, quantify the point and nonpoint source loads of these chemicals and agents. We used the most recent available data . Where gaps in data occurred or where data were considered to be of low quality, we used estimates based upon typical values reported in the literature.

Elements, compounds, and biological agents were selected for the study based upon several criteria:

- Potential to degrade the quality or impair the use of Massachusetts Bays water;
- Inherent toxicity to environmental receptors or humans;
- Potential to be bioaccumulated by marine organisms;
- Environmental persistence;
- Information indicating that Massachusetts Bays water or sediment is being "enriched" as a result of loading.

Based on these criteria, the following general categories of materials were selected for the study:

- Total suspended solids;
- Oxygen-consuming substances (biological oxygen demand or BOD);
- Nutrients, including nitrogen and phosphorus;
- Polynuclear aromatic hydrocarbons (PAHs);
- Environmentally persistent, chlorinated organic compounds (e.g., PCBs, pesticides);
- Selected metals, including lead, cadmium, chromium, mercury, copper, arsenic, selenium, beryllium, silver and nickel;

- Pathogens (viruses and bacteria).

For some of the selected materials, insufficient data were available to compare the relative magnitude of various sources of the contaminant to the bays system. Consequently, we made this comparison only for total suspended solids, BOD, nitrogen, phosphorus, oil and grease, PAHs, PCBs, cadmium, copper, chromium, lead, copper and mercury. Because loads of many of these contaminants depend upon the total freshwater flow from the drainage basins, we also made the comparison for total flow. Comparisons were not made for pathogens or pathogen indicators, they are a greater problem on a local rather than a bay-wide scale.

Estimates of loadings were made for several types of inputs, each with different spatial scales:

1. Point Sources - estimates for all major point sources throughout the drainage areas feeding the Massachusetts Bays system.

2. Coastal Point Sources - estimates for major point sources that discharge directly to coastal embayments or to the open bay waters;

3. Rivers - estimates for point sources by river and for total loadings associated with each major river discharge to the bays; we considered 27 river systems;

4. Runoff from Drainage Basins - estimates of runoff in five drainage basins: Merrimack River, North Shore, Boston Harbor, South Shore, and Cape Cod Bay;

5. Groundwater Discharges - estimates for selected pollutants and drainage basins.

6. Coastal Runoff - estimates of runoff directly from the coast into open bay waters or embayments; this analysis considers a zone of 0.5 miles from the coast as contributing directly as coastal runoff; these estimates are made for each drainage basin;

7. Locations of In-place Sediments and Hazardous Waste Sites within 500 Feet of a Surface Waterbody Draining to Massachusetts Bays - locations of such sediments or waste sites;

8. Ocean Disposal of Dredged Material - a direct input to the bays at the DAMOS site;

9. Atmospheric Deposition - estimates for the major areas of the bays.

loadings from atmospheric deposition onto the water surface and disposal of dredged material at the DAMOS site equaled the total load to the system.

Method B estimated loads by drainage area as the sum of (1) major NPDES discharges for only the coastal discharges; (2) river discharges; (3) runoff from coastal areas, defined as the area within 0.5 miles of shore (except for Cape Cod Bay for which total runoff was used); and (4) groundwater flow for the selected parameters and drainage basins. Similar to Method A, loads from atmospheric deposition and disposal of dredged material were added to this sum to provide an overall estimate of loadings to the Massachusetts Bays system.

Because the data used to estimate inputs of contaminants to the system derive from many sources on many spatial scales, each estimate contains some inherent uncertainty. In some instances, there were no available measurements, and data were estimated from literature values or from extrapolations from similar systems. Most data on runoff, for example, were obtained from the NOAA National Coastal Pollutant Discharge Inventory (NCPDI), a database that probably provides the best available estimates of runoff for the region but which relies on extrapolations from "typical" conditions. Data on loads from river flow were also frequently estimated from typical values reported in the literature rather than based upon actual data.

Estimates of Loadings

Estimates of relative inputs of freshwater and contaminants to the Massachusetts Bays system are summarized in Figures i-iii. Most of our estimates of loadings to the Massachusetts Bays system use maximum levels we have estimated. Every estimate is subject to uncertainty, so in some instances, we present data as a range.

Freshwater Flow

Freshwater flow was calculated using only Method B. Groundwater flow was calculated only for Boston Harbor and Cape Cod Bay. Because they dominate the NPDES discharges, flows from sewage treatment plants (POTWs) were used to estimate the point sources of flows.

Using this method, the Merrimack River accounted for 52% of the freshwater flow to the system. Rainfall accounted for 28%. If the Merrimack River were excluded from calculations, rainfall would account for 58% of the total input of freshwater to the bays. While nonpoint sources dominated the inputs from most of the drainage basins, inputs from the Deer and Nut Island POTWs dominated the flow into Boston Harbor.

Our estimates did not include estimates of inputs of freshwater from the Gulf of Maine. This source may in fact provide the greatest inputs of freshwater to the system, so its exclusion is significant.

The estimates that we do provide are subject to uncertainty. Annual river flows were estimated using several techniques, depending upon whether gauge measurements were available. Seasonal and year-to-year variability in flow is also high. This variability will affect the input of contaminants as well as water to the system, so it contributes a major source uncertainty to our estimates of contaminant loads.

Total Suspended Solids

Loadings of total suspended solids were calculated using both methods. No data were available to consider atmospheric inputs, but inputs from other sources ranged from 299,000-555,000 mt/yr. Disposal of dredged material was a major source of suspended solids, accounting for 31% of the Method A and 60% of the Method B estimate. Because dredged material disposal occurs at only one designated site within the system, this source affects a limited area.

Biochemical Oxygen Demand (BOD)

Estimates of BOD loadings were almost identical using the two methods, about 180,000 mt/yr. Most of the loads were due to inputs from NPDES discharges. The Boston Harbor NPDES outfalls accounted for approximately one half of the coastal NPDES inputs to the bays.

Total Nitrogen

The NPDES discharges also accounted for major portions of the inputs of nitrogen to the system, 66% of 28,000 mt/yr for the Method A and 43% of 36,000 mt/yr for the Method B estimate. For Method A, runoff and atmospheric deposition were other important sources. For Method B, river discharges accounted for 37% of the inputs.

Groundwater discharges were calculated only for Boston Harbor and Cape Cod Bay, but in those systems, groundwater appeared to be an important nearshore source. For Cape Cod Bay, loadings via groundwater were estimated at about 320 mt/yr, while loadings from runoff were 31 mt/yr.

Total Phosphorus

Approximately 3,880-4,100 mt/yr total phosphorus is introduced to the bays using Methods A and B. These estimates did not include inputs from dredged material. However dredged material accounted for only about 5% of the inputs of the nitrogen, the other nutrient examined. NPDES discharges accounted for 82% of the Method A and 71% of the Method B estimate.

Oil and Grease

Method A estimated that 13,000 mt/yr oil and grease are introduced into the bays. Method B estimated approximately half that amount, however, Method B did not consider river discharges. Based upon the available information, nonpoint source runoff is probably the major source on oil and grease to the bays. Dredged material is also a major source of oil and grease, accounting for approximately 19% of the total load.

PAHs

We found considerable variability in the estimates of PAH loads to the system, largely because few measurements of PAH estimates have been made. Our estimates were therefore based upon ranges of values that we considered typical. Using our higher estimates, which assumed that municipal effluents contain average concentrations of PAHs of about 10 ug/l, Methods A and B resulted in approximately the same input, 13,100-13,700 kg/yr. The NPDES discharges to Boston Harbor dominated these estimates. Those values probably represent an extreme worst-case estimate.

More recent, but preliminary, data, indicate that average concentrations of PAHs in municipal effluents are far lower than assumed by our high estimates, about 0.1 ug/l. Even using an average concentration of 1 ug/l, the total loads were 1,819 kg/yr for Method A and 2,200 kg/yr for Method B. The NPDES discharges accounted for one third to one half of these estimates. Using the lower estimates, atmospheric deposition appeared to be an important source of PAHs to the system, 52% for Method A and 43% for Method B.

PCBs

Total loads of PCBs to the bays was approximately 2,600 kg/yr using both Methods A and B. The similarity of these estimates results from the dominance of our estimate of loads from atmospheric deposition. This estimate was based upon data collected during the mid 1970s, and the current value may be less.

Estimated of inputs of PCBs from NPDES discharges ranged from 416-468 kg/yr, about 20% of the total load. These estimates were based upon data that were below detection limits and that indicated that the MWRA effluents accounted for less than 250 kg/yr. Recent, preliminary data indicate that this detection estimate was too high. Similar to PAHs, the estimates for inputs from NPDES discharges represent a worst case.

Cadmium

There is considerable uncertainty about the estimates of inputs of cadmium to the bays, because few measurements have been made of cadmium inputs from point sources. Using high estimates of these values, we calculated inputs of 8,020-14,700 kg/yr. NPDES discharges accounted of 34% of the Method A and 17% of the Method B estimates. Runoff accounted for 30% of the Method A estimate, and river discharge accounted for 66% of the Method B estimate, assuming an average concentration in rivers of 1 ug/l.

Chromium

Similarly, few data were available for chromium concentrations in NPDES discharges. Using high estimates for chromium in NPDES discharges for Methods A and B, 84,000-120,000 kg/yr enter the bays. NPDES discharges accounted for 53% of the Method A estimate and 35% of the Method B estimate. Runoff accounted for 24% of the Method A estimate. Rivers accounted for 47% of the

Method B estimate, assuming an average concentration of chromium in river waters of 6 ug/l.

Copper

Methods A and B provided similar estimates of copper inputs to the bay, 150,000 and 190,000 kg/yr. Point and nonpoint sources were both important contributors to the overall load. NPDES discharges accounted for 57% and 37% of the Methods A and B estimates. Runoff accounted for 25% of the Method A, and rivers accounted for 50% of the Method B estimate, assuming an average concentration in river water of 10 ug/l.

Lead

Lead inputs, however, were dominated by estimates of inputs from nonpoint sources. Method A estimated that 470,000 kg/yr enter the bays. Method B estimated 540,000 kg/yr. NPDES discharges accounted for less than 10% of these estimates. Runoff accounted for 42% of the inputs, using Method A and assuming concentrations in CSOs of 92 ug/l. Atmospheric deposition was also an important source of lead, accounting for 45% of the Method A and 39% of the Method B estimates.

Zinc

Zinc inputs were estimated as 419,000-536,000 kg/yr using Methods A and B. NPDES discharges, runoff, and atmospheric deposition contributed approximately equally to these values. NPDES discharges accounted for about 35% of the total load. Assuming an average concentrations of 30 ug/l, rivers accounted for 53% of the Method B estimate.

Mercury

Mercury inputs were estimated using only Method A. Point source loads were difficult to estimate, because the only available data were for the MWRA outfalls into Boston Harbor. Those data included only values that were below detection limits. Extrapolations from these limited data therefore represented a worst-case estimate. Using the limited available information, point sources were the major sources of mercury to the bays, accounting for about one half the total load. Runoff, dredged material, and atmospheric inputs also contributed to the mercury loads.

Qualifications and Data Gaps

In addition to the uncertainties inherent in each of the estimates of pollutant inputs to the bays, there are other factors that will affect any interpretation or use of the information included in this report. For example, the fate and effects of contaminants entering the system will differ, depending upon the methods by which they are introduced. Atmospheric deposition, for example, is spread out over a wide area, while dredged material is placed into a specific site.

Inputs also will vary seasonally. River flow, nonpoint source runoff, and groundwater discharge are all expected to vary seasonally. Stormwater runoff will vary not only seasonally, but periodically, when large rainfalls increase runoff from storm drains and CSOs.

Also, seemingly constant inputs, such as those from the major NPDES discharges, may vary with the changes in the hydrodynamics of their receiving waters. Concentrations of contaminants in the receiving waters may be higher during periods of low flow than they are during periods of high flow.

Several data gaps were identified during preparation of the report:

- Sources of PAHs to the marine environment - few data were available on PAHs.
- Elevated levels of contaminants in sediments. Although heavily contaminated sediments have been identified in the report, and we have summarized available data, we have not determined how to consider them as sources. Resuspension from the sediments has not been considered in our comparison of relative magnitude of sources of contaminants to the bays.
- Varying spatial scales. We assessed loads from sources that vary in spatial scale. However, we have not determined how the different spatial scales affect the fate and effects of various contaminants.
- Oil spills. Oil spills and other infrequent, large-scale events were not considered.
- Marine pump-out facilities. We did not consider pump-out facilities or other discharges from marinas.
- Groundwater. Loadings of nitrogen from groundwater appears to be an important source of nutrients to embayments along the shores of Cape Cod. Concentrations of nutrients should be measured within these embayments to verify this source.
- Synthetic organic compounds. Few data are available on pesticides and other synthetic organic compounds, and their loads were not evaluated in this report.

Figure i. Loads of conventional pollutants by drainage area.

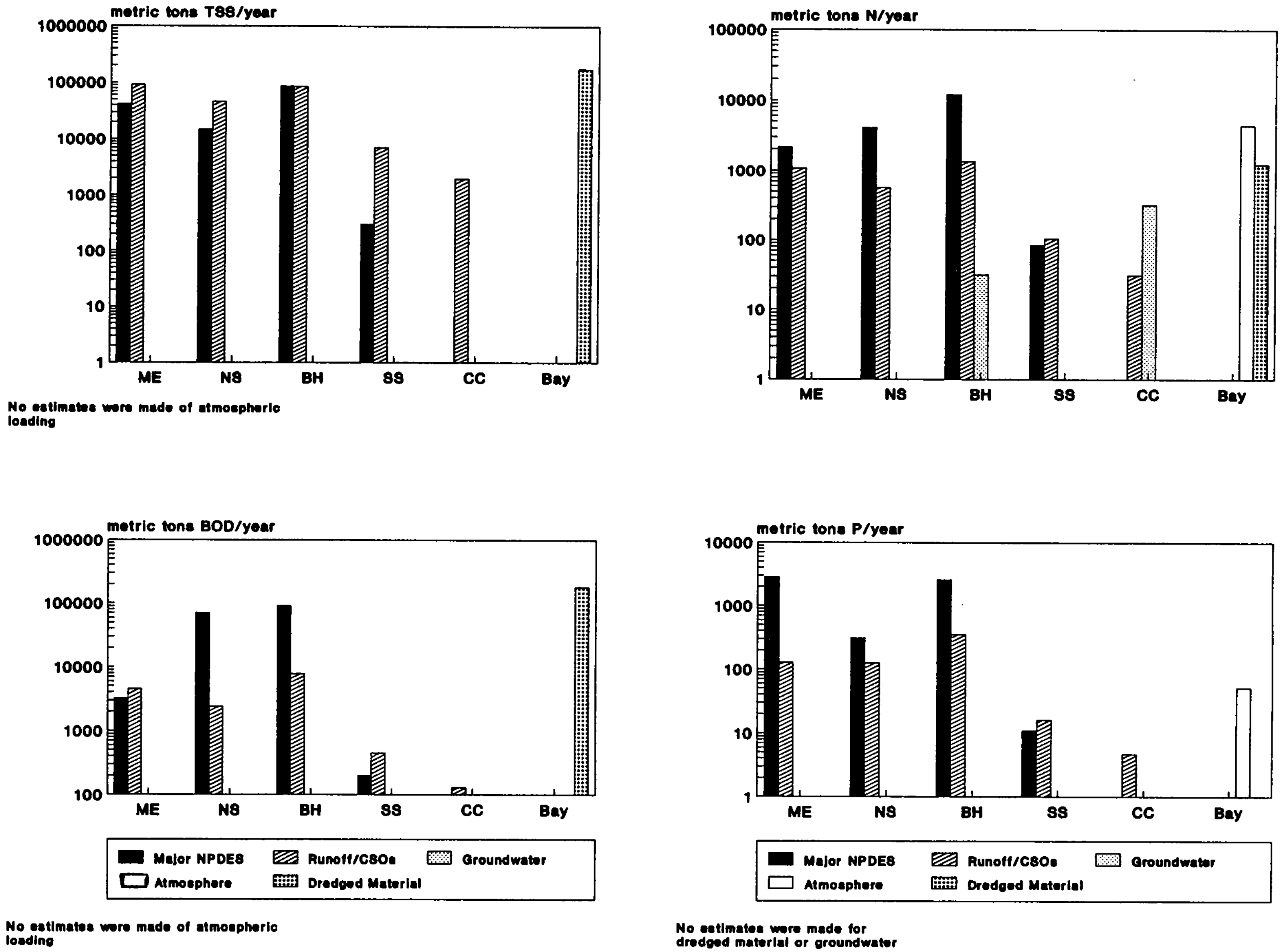


Figure ii. Loads of organic pollutants by drainage area.

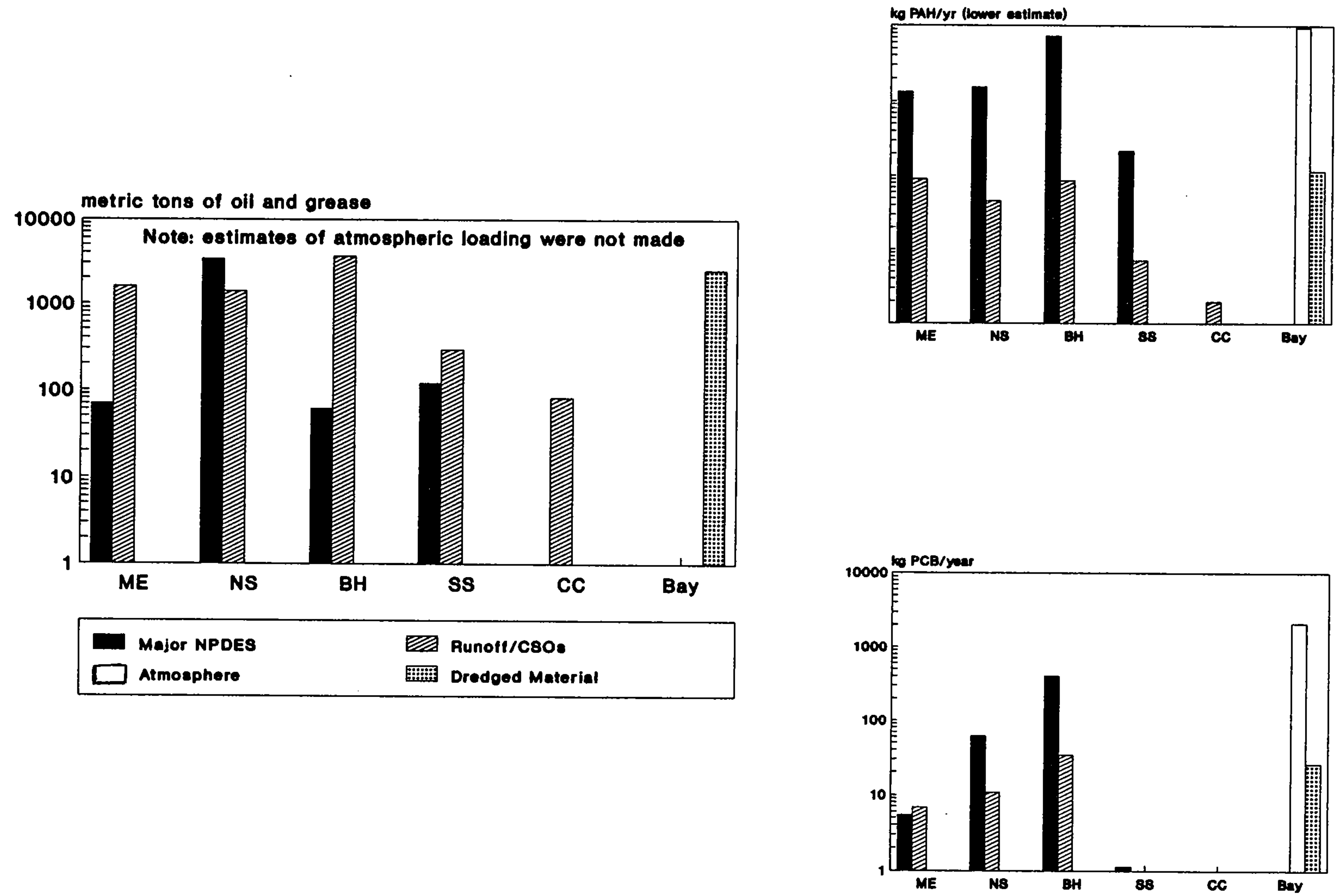
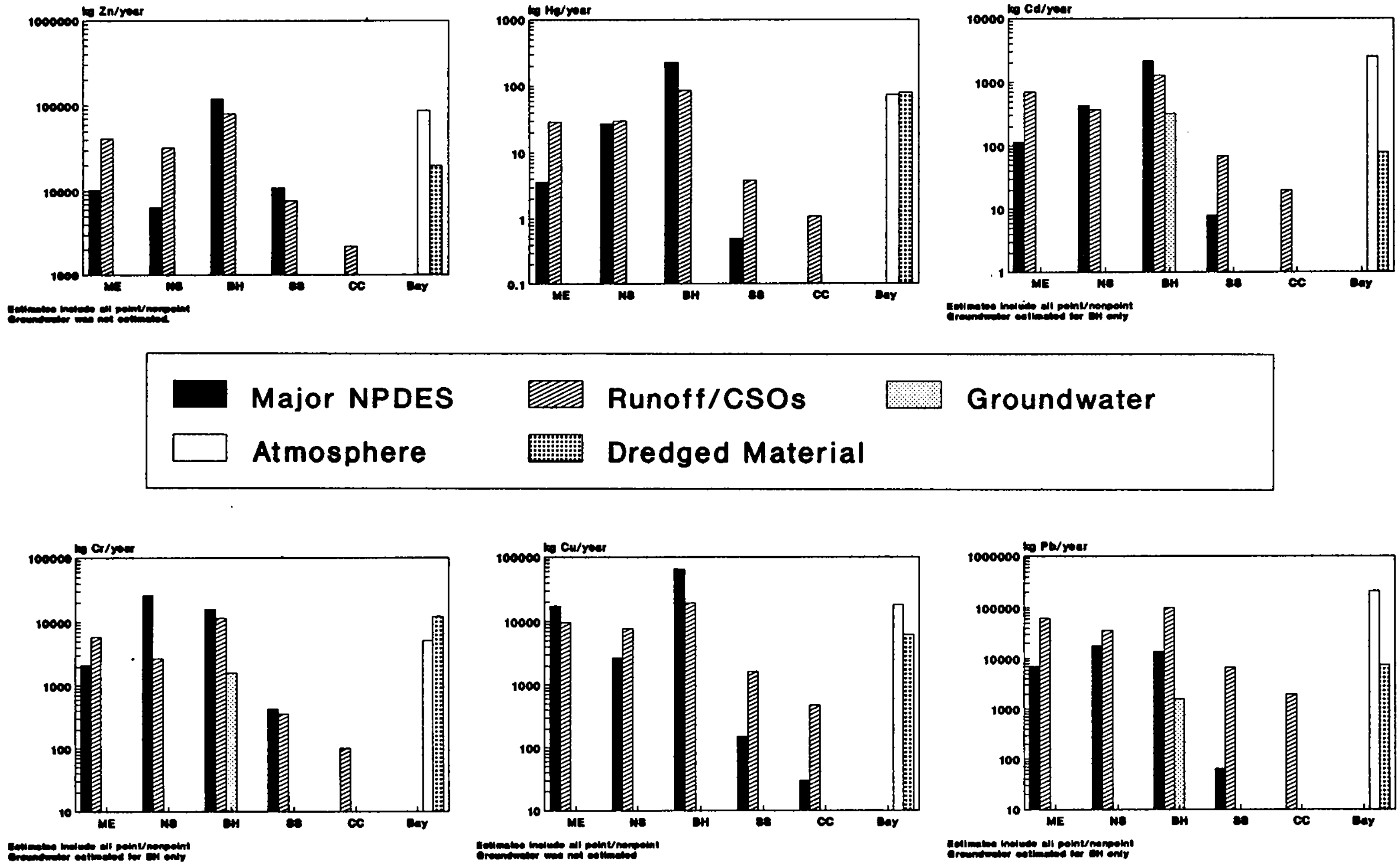


Figure iii. Loads of metals by drainage area.



1.0 INTRODUCTION

This report identifies and quantifies sources and loadings of pollutants to the Massachusetts Bays system. This report provides the results of Task 1 of the Massachusetts Bays Program (MBP). The MBP is jointly administered by the U.S. Environmental Protection Agency (EPA) and Massachusetts Coastal Zone Management (CZM). The MBP is developing a plan for conservation and management of the estuarine waters from the New Hampshire border to Race Point on Cape Cod. The plan will cover Massachusetts and Cape Cod bays.

1.1 Objectives

Over the past several years, investigators and regulators have approached marine pollution and waste management issues within a risk assessment/risk management framework (e.g., Bierman et al., 1985). The Massachusetts Bays Program embodies many of the key elements of this framework. In simple terms, the overall elements of any marine risk assessment/risk management program include the following:

1. Hazard Identification (what conditions are thought to pose a hazard)
2. Source Identification and Characterization
3. Exposure Assessment
   - Fate and Transport studies
   - Estimates of Exposure Point Concentrations
4. Effects Assessment
   - Acute, subchronic, and chronic effects on marine organisms
   - Acute, subchronic, and chronic effects on humans using marine resources
5. Risk Characterization
6. Risk Management
   - Where can efforts be best spent to reduce risks?

This report provides information related to the first elements of the risk assessment/risk management framework:

1. Hazard identification
2. Source identification and characterization

The objectives are to identify and characterize the compounds or biological agents and estimate the loadings of these pollutants to the Massachusetts Bays system. This information has been developed to identify specific sources of the compounds. Such information is important for facilitating sound management decisions.

In summary the proposed objectives for Task 1 of the MBP are:

1. Identify chemical compounds and biological agents that may pose hazards to the Massachusetts Bays system;

2. Identify and characterize point and nonpoint sources and loadings of these compounds and agents;

3. Gather and organize information to be compatible with fate and transport modeling efforts and with regulatory and research programs used to make decisions concerning the need for and efficacy of source controls;

4. Integrate information from the concurrent Massachusetts Water Resources Authority (MWRA) program and address data gaps as needed.

1.2 Report Organization

The technical approach used in the study is presented in Chapter 2. A discussion of the various watersheds that feed the Massachusetts Bays system is provided in Chapter 3 and provides a basis for organizing data on point and nonpoint sources. The locations and magnitudes of point and nonpoint sources are described in Chapters 4 and 5 respectively. An overview of contaminant loadings and an assessment of these loadings is given in Chapter 6. This chapter also identifies sources of uncertainty and data gaps in the estimates of loadings.

2.0 TECHNICAL APPROACH

2.1 General Approach

The approach employed in this study was to identify important pollutants being discharged to the Massachusetts Bays system, quantify to the extent possible the point and nonpoint source loads of these chemicals, and organize this information at several spatial scales. An effort was made to obtain the most recent data available. In some cases, where data gaps or data of poor quality existed, estimates were made based on available data in the literature or based on extrapolation from similar systems. An example is the loading of lead via National Pollutant Discharge Elimination System (NPDES) outfalls. We recognize that lead will probably be present in virtually all Publicly Owned Treatment Works (POTW) effluents. However, it is not measured in all effluents (i.e., it is not reported in their Discharge Monitoring Reports). To obtain an estimate of loadings, we developed a ratio of lead to total suspended solids (TSS) for other POTWs in the system and applied this ratio to the TSS levels measured at the POTWs for which there were no lead data.

Wherever possible we have identified uncertainties associated with the data. We have also included an annotated bibliography of data sources as Appendix A of this document. This bibliography provides additional information on the data bases and also provides some basis for evaluating the quality of underlying data.

2.2 Selection of Compounds and/or Biological Agents

The assessment considered a specific set of compounds and/or biological agents judged to have the potential for posing a hazard to the Massachusetts Bays System. The selection of these compounds was a critical part of the program because it provides the framework for subsequent data collection and analysis efforts.

Several criteria were considered in selecting the compounds and/or biological agents to be included in the analysis. The primary criteria are the following:

- The potential for the compounds to degrade the quality or impair the use of Massachusetts Bays water;
- The inherent toxicity of the chemical to environmental receptors or humans;
- The potential for the chemical to be bioaccumulated by marine organisms;

- The environmental persistence of the compounds;
- Information indicating that Massachusetts Bays water or sediment is being "enriched" as a result of the loading of the compound.

Based on the criteria provided above the following general categories of materials were selected for the analyses:

- Total suspended solids
- Polynuclear aromatic hydrocarbons (PAHs);
- Environmentally persistent chlorinated organic compounds (e.g., PCBs, pesticides);
- Selected metals including lead, cadmium, chromium, mercury, copper, arsenic, selenium, beryllium, silver and nickel;
- Oxygen consuming substances (BOD);
- Nutrients;
- Pathogens (viruses/bacteria in wastewater).

2.3 Consideration of Spatial Scales

Loadings to Massachusetts Bays are estimated at several spatial scales. This has been done in recognition of the fact that environmental problems may be manifested at various spatial scales and to provide a basis for identifying which sources or which regions are most "important" with regard to loadings to Massachusetts Bays. The spatial scales included in the analyses are as follows:

1. Point Sources - estimates are provided individually for all major point sources throughout the drainage areas feeding the Massachusetts Bays system;
2. Coastal Point Sources - estimates are provided individually for major point sources that discharge directly to coastal embayments or to the open bay waters;
3. Rivers - estimates are provided for point sources by river and for total loadings associated with each major river discharge to the bays; twenty-seven river systems are considered in the analysis;

4. Drainage Basins - estimates are provided for point sources, runoff, and, in few cases, groundwater discharges; the system has been broken up into five drainage basins for the purpose of this analysis: Merrimack, North Shore, Boston Harbor, South Shore, and Cape Cod (Figure 1);

5. Coastal Runoff - estimates are provided for runoff directly from the coast into open bay waters or embayments; this analysis considers a zone of 0.5 miles from the coast as contributing directly as coastal runoff; these estimates are made for each drainage basin;

6. Locations of In-place Sediments and Hazardous Waste Sites within 500 Feet of a Surface Waterbody Draining to Massachusetts Bays - this information is presented in terms of the locations of such sediments or waste sites;

7. Ocean Disposal of Dredged Material - this is considered as a direct input to the bays and occurs at the DAMOS site;

8. Inputs of Atmospheric Deposition - these estimates are provided for the major areas of the bays.

Source information organized within these various spatial scales should help provide linkage between the fate and effects of chemicals in the bays and specific sources.

2.4 Quality Assurance

The analysis presented in this report relies upon data obtained from a variety of sources which may differ in quality and level of documentation. To provide some basis for evaluating the quality of the underlying data each data source is described in Appendix A along with comments related to the apparent quality of the data. A detailed review of these data was beyond the scope of this program. Nevertheless, the probable ranges and values of data were assessed using appropriate "reality checks". Where data were suspect we nevertheless used it, but provided qualifications regarding its usefulness. Data judged to be unreliable are not used in Chapter 6 where an assessment is made of overall loadings of pollutants to the Bays.

The effort involved entry of many data points into spreadsheets and calculations of loadings using these spreadsheets. Quality Assurance included a review of data entry and generally several reviews of calculations.

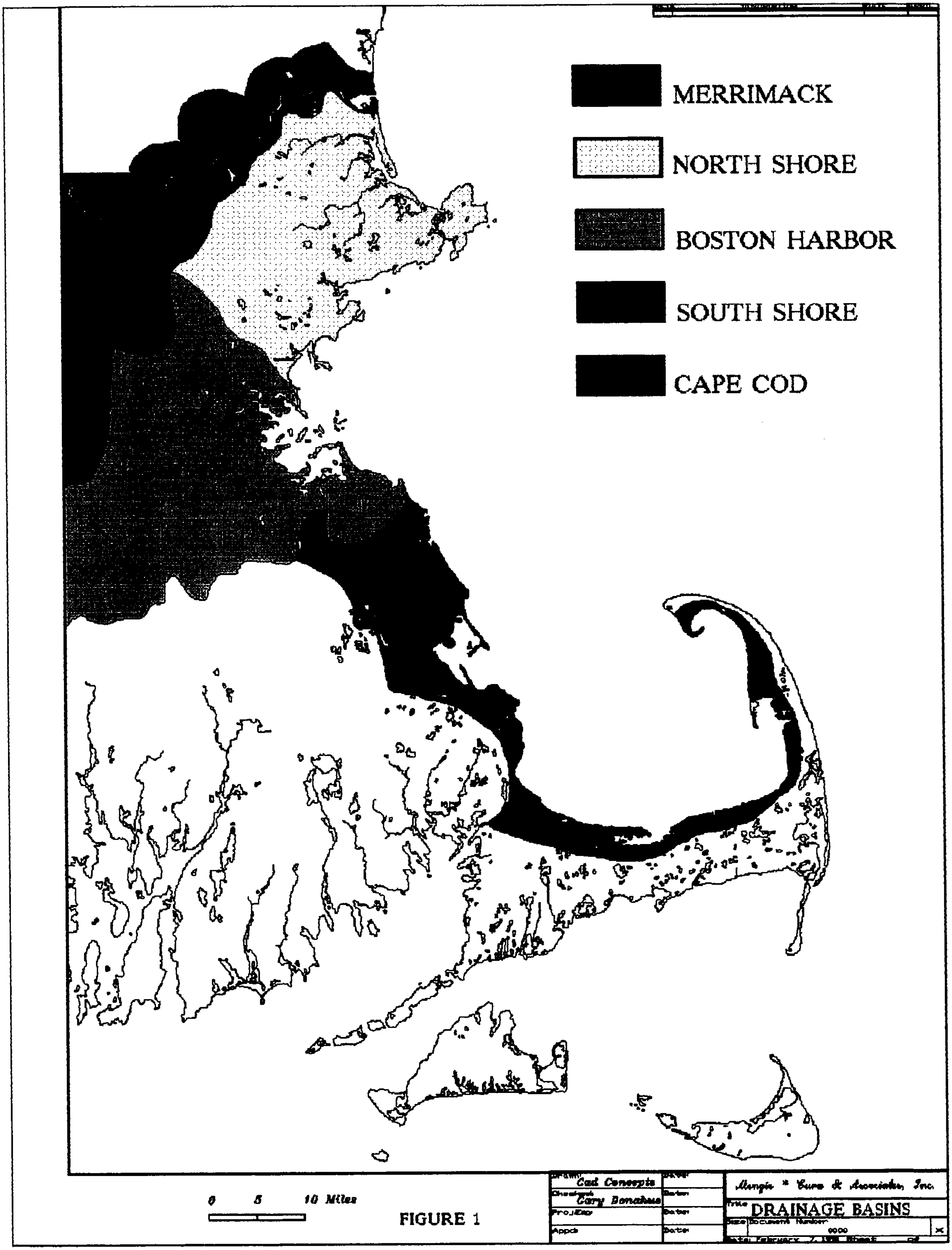

MERRIMACK
NORTH SHORE
BOSTON HARBOR
SOUTH SHORE
CAPE COD
0 5 10 Miles
Cad Concepts
Gary Donahue
Mengis * Cure & Associates, Inc.
DRAINAGE BASINS
9000

FIGURE 1

2.5 Integration with Other Programs

Members of the study team participated in exchanges of information with other MBP Project teams. In addition, information gathered as part of meetings with citizen's groups was utilized to define and/or supplement data gathering efforts.

2.6 Uncertainty/Sensitivity Analysis

This project yields a variety of estimates of loadings. Underlying these estimates are various statistical distributions and assumptions. Therefore, there is a certain amount of uncertainty associated with each estimate. In most cases we have provided ranges for estimates and have checked estimates in several ways. Underlying assumptions are identified in Chapters 4 and 5 of this report.

2.7 Source Types

The Water Quality Act of 1987 (PL 100-4) and its predecessor legislation identifies two categories of water discharges: point and nonpoint sources. However, it is generally convenient to consider them in the following way:

- Traditional point sources: discharges from POTWs and industrial wastewater discharges.
- Nontraditional point sources: discharges that are defined as point sources under the act but that are driven by additional considerations such as meteorological conditions, e.g., separate municipal storm sewers, combined sewer overflows.
- Nonpoint sources: everyting else, including runoff from nonurban areas, atmospheric deposition, interflow and groundwater inputs, inplace sediments, and seeps.

We used these definitions because while the nontraditional point sources are treated as point sources under the law, they behave in fact like nonpoint sources, and similar methodological approaches are needed to assess them.

3.0 WATERSHED CHARACTERIZATION

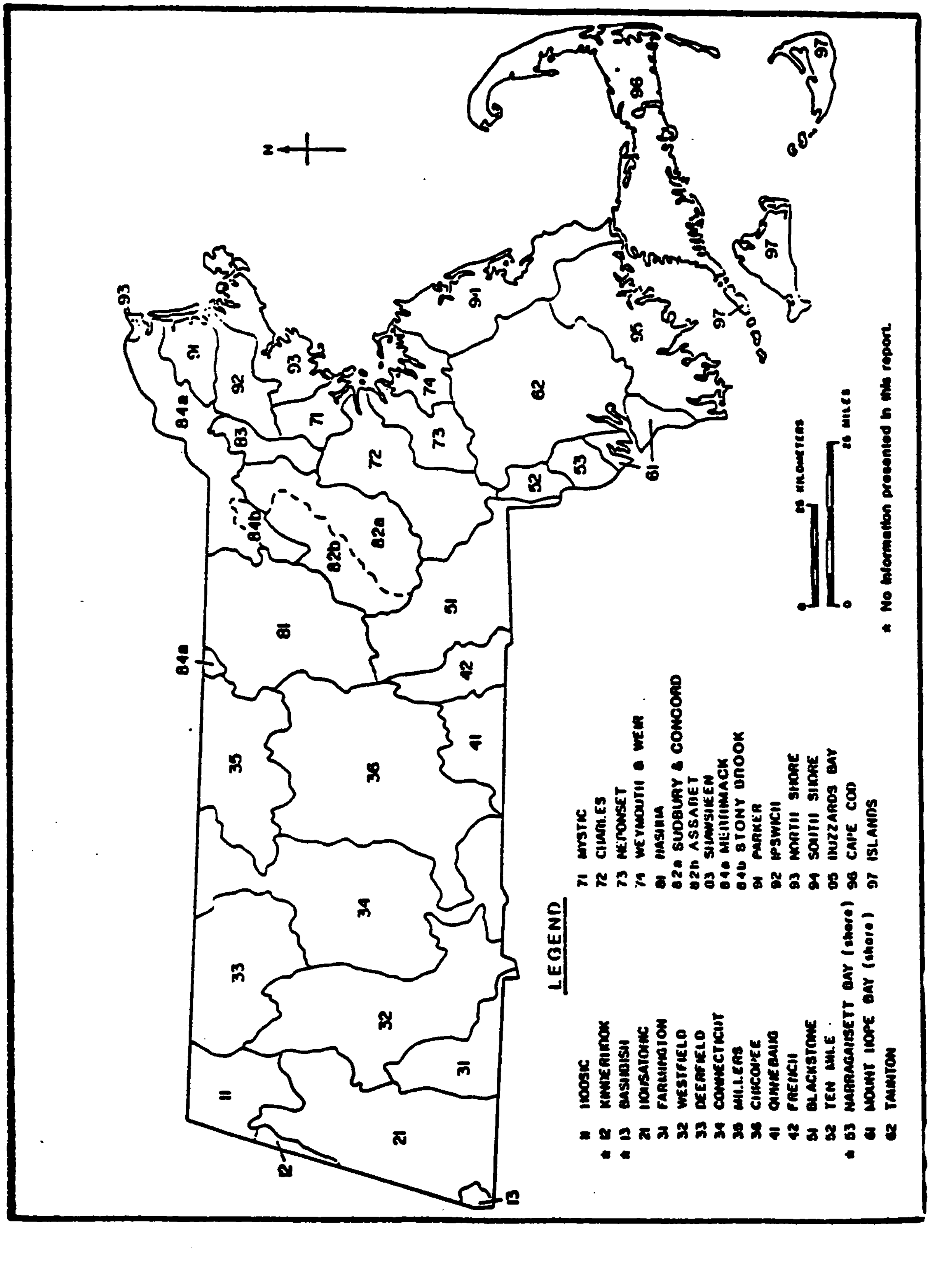
3.1 Drainage Areas

The Massachusetts Bays system was organized into five drainage basins within which twenty-seven major rivers were identified (Figure 1). These drainage basins can be compared to those established by the Massachusetts Department of Environmental Protection (DEP) (Figure 2). The drainage basins selected for this analysis (Figure 1) were established based on the extent of information available on land use in the National Oceanic and Atmospheric Administrations (NOAA) National Coastal Pollutant Discharge Inventory (NCPDI) file. The United States Geological Survey (USGS) and County boundaries are shown in Figures 3 and 4 respectively. Data in the NCPDI were reported by drainage basins defined by the USGS cataloging units, counties, and units called HUCOs, unique areas made up by overlaying county lines upon the lines defined by the USGS cataloging units. Because the areal resolution of the USGS units was too coarse to mimic the five drainage areas, HUCOs or portions of HUCOs were attributed to each drainage area. The spatial relationships between the drainage areas selected for this study and those used by DEP, NOAA, and USGS are summarized in Table 1. In one instance, Cape Cod Bay, the drainage area was a portion of the DEP drainage area.

Table 1. Drainage areas used in this study and their relationships to other designated drainage areas.

Drainage Area	Massachusetts DEP Coastal Drainage Area	NOAA HUCO (County x USGS Cataloging Unit)
Merrimack River (1,527 km2)	84 (1,960 km2)	30, 32, 33, 34
North Shore (1,553 km2)	91, 92, 93 (1,060 km2)	29, 31, (40%)35, (25%)37
Boston Harbor (1,425 km2)	71, 72, 73, 74 (1,560 km2)	(60%) 35, 36, (75%) 37, 38, 42
South Shore (636 km2)	94 (681 km2)	39, (60%) 43
Cape Cod Bay (117 km2)	Part of 96	(30%) 45

Figure 2. Drainage areas used by the Massachusetts Department of Environmental Protection



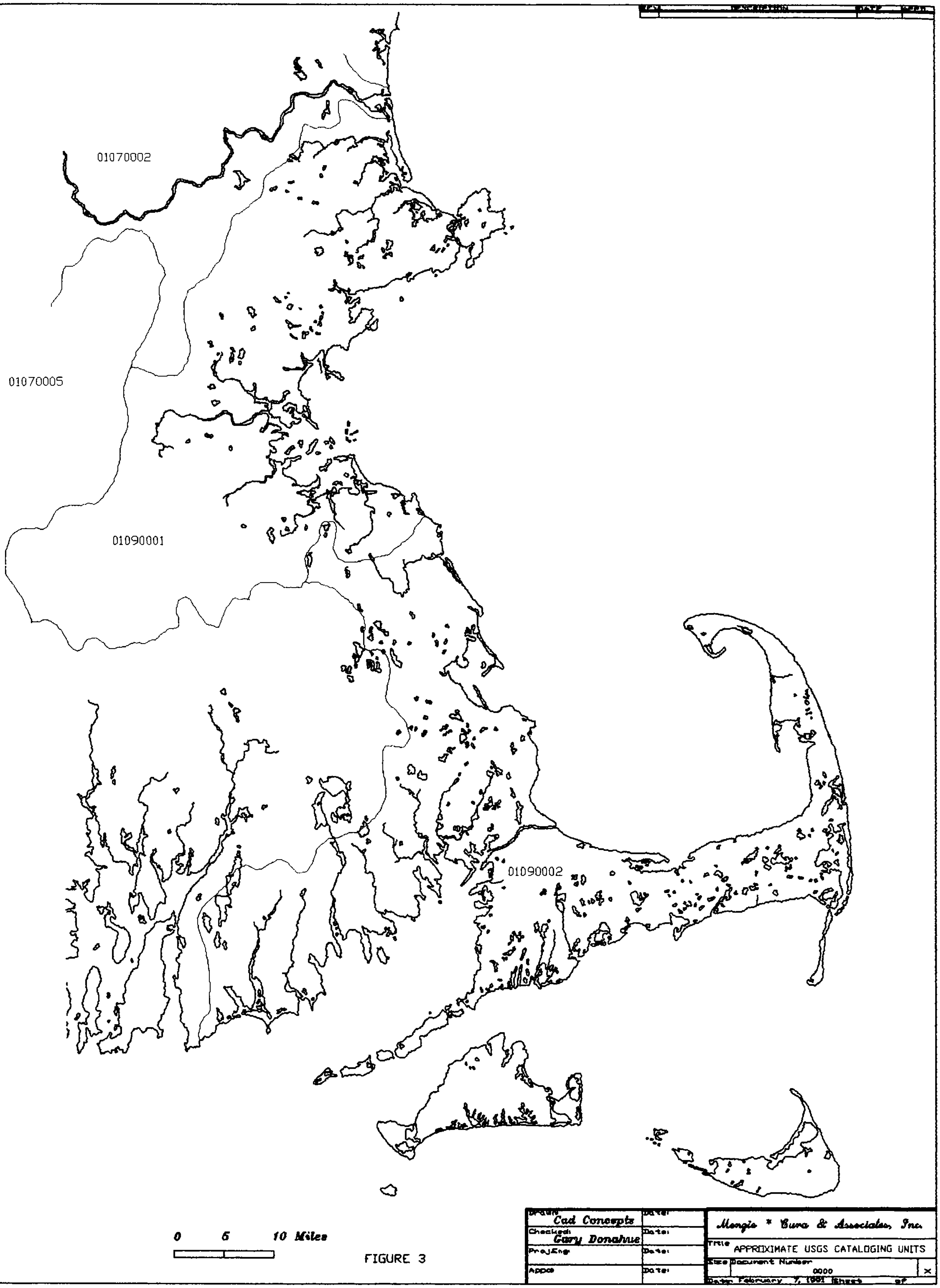

01070002
01070005
01090001
01090002
0 5 10 Miles
Drawn
Cad Concepts
Date:
Checked:
Gary Donahue
Date:
ProjEng
Date:
Appd
Date:
Mengis * Cura & Associates, Inc.
Title
APPROXIMATE USGS CATALOGING UNITS
Size
Document Number
0000
X
Date: February 7, 1991
Sheet of

FIGURE 3

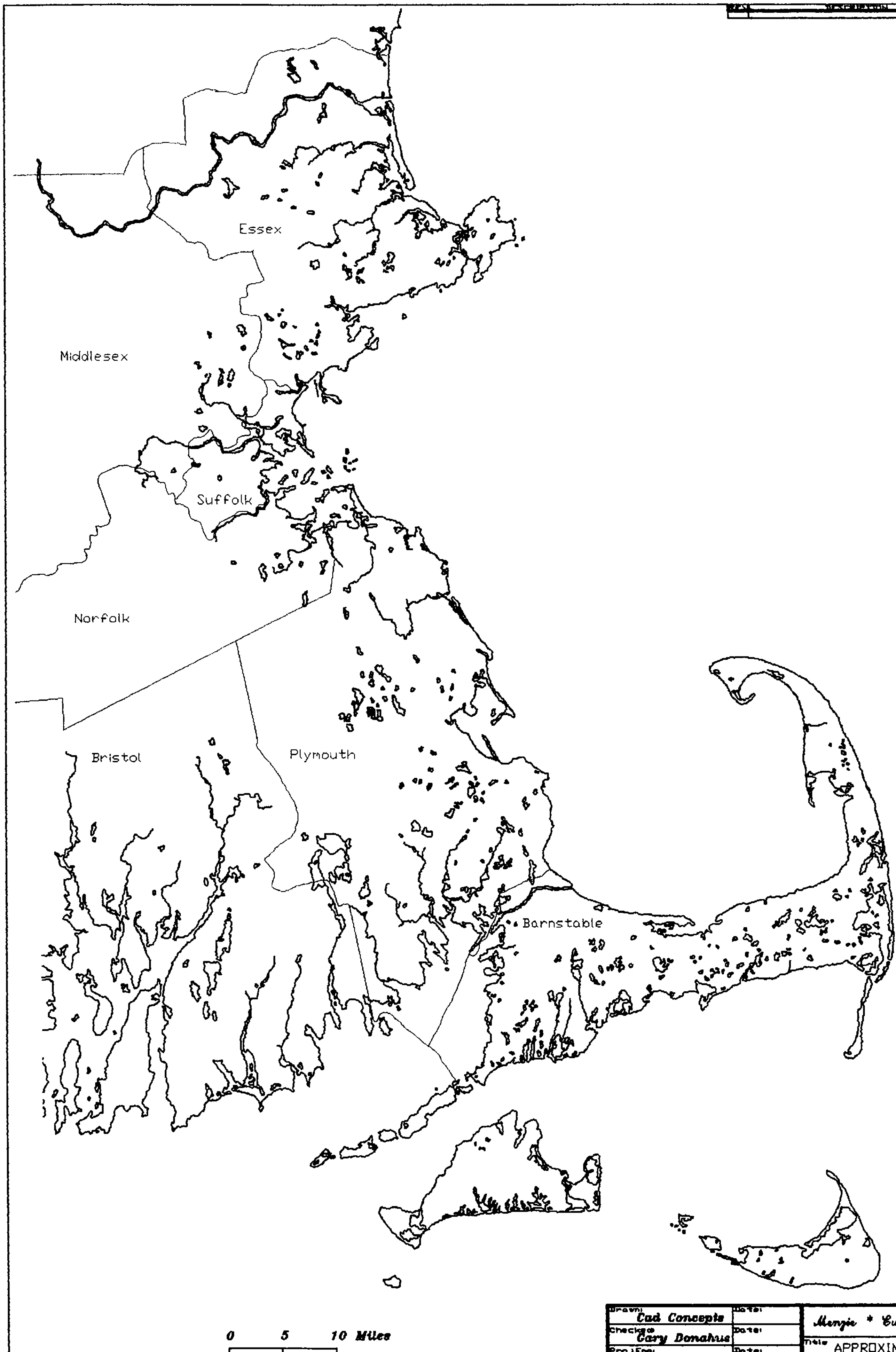


FIGURE 4

Drawn: Cad Concepts	Date:	Menzie * Cura & Associates, Inc.
Checked: Gary Donahue	Date:	Title APPROXIMATE COUNTY LINES
Proj.Eng:	Date:	Size Document Number 0000 X
Appd:	Date:	Date: February 7, 199[illegible] Sheet of

Land-use characteristics were developed for each of the five drainage areas using information presented in the NCPDI. Seven categories of urban environment were used as well as nonurban (Table 2). The total study area for the five drainage areas is 5,270 km^2. The largest drainage area is the North Shore (1,550 km^2) and the smallest is Cape Cod (118 km^2). The drainage area with the highest percentage of urban environment is Boston Harbor (51%) and the area with the lowest percentage is the South Shore (17%).

Table 2. Land use within the various drainage areas (km^2).

Land Use	Merrimack	North Shore	Boston Harbor	South Shore	Cape Cod	Total
Residential	317 (73%)	377(68%)	516(71%)	82.3(76%)	23.4(67%)	1316(71%)
Commercial	67.4 (16%)	81.9(15%)	107(15%)	6.0(6%)	3.9(11%)	266(14%)
Industrial	3.7 (1%)	14.0(3%)	13.8(2%)	0.9(1%)	0.3(1%)	32.7(2%)
Transport.	17.2 (4%)	25.4(5%)	29.8(4%)	9.3 (9%)	1.2(3%)	82.9(4%)
Industrial /Commercial	0.6	1.5	2.7	0.2	0.3	5.3
Mixed Urban	3.2 (1%)	0.2	2.1	2.5	0.9(3%)	8.9
Total Urban	433 (28%)	553(36%)	727(51%)	108(17%)	35(30%)	1856(35%)
Non-Urban	1104(72%)	1000 (64%)	698 (49%)	528 (83%)	83 (70%)	3413 (65%)
Total	1537	1553	1425	636	118	5270

3.2 River Systems

Twenty-seven rivers were considered in this analysis (Table 3). Annual flows for each river were estimated from a combination of gauge measurements and estimates of river discharge for drainage areas. For rivers with gauges, statistical summaries of stream flow data were employed to estimate average flow. All USGS flow data are reported in units of cubic feet per second. For our loading analysis, flows were converted to cubic meters per second.

Table 3. Estimated annual river discharge to Massachusetts Bays (m^3/s)

	Drainage area at gauge (square miles)	Total drainage area (square miles)	Annual flow at gauge (m3/s)	Adjusted gauged flow (1) (m3/s)	Estimated flow from drainage area (2) (m3/s)
Ipswich River	125.00	155.00	5.21	6.46	7.46
Essex River		9.42			0.45
Rowley River		9.92			0.48
Merrimack River	4425.00	5014.00	215.19	243.84	241.22
Parker River	21.30	59.50	1.00	2.80	2.86
Annisquam River		2.32			0.11
Bass River		1.38			0.07
North River					0.00
Danvers River		12.36			0.59
Crane River		5.72			0.28
Pines River		10.00			0.48
Mystic River	62.70	66.00	0.78	0.82	3.18
Saugus River		48.20			2.32
Chelsea River					0.00
Charles River	227.00	319.00	8.60	12.09	15.35
Neponset River	34.70	116.00	1.51	5.03	5.58
Weymouth Fore River	27.60	130.58	0.06	0.28	6.28
Weymouth Back River	4.29	91.00	0.26	5.58	4.38
Weir River	14.60	25.93	0.03	0.05	1.25
South River	7.59	24.00	0.06	0.18	1.15
North River	30.30	81.00	1.76	4.71	3.90
Green Harbor River		7.31			0.35
Jones River	15.70	29.60	0.91	1.71	1.42
Town Brook	9.04	9.04	0.31	0.31	0.43
Eel River	14.70	14.70	0.51	0.51	0.71
Beaver Brook Dam	5.52	5.52	0.18	0.18	0.27
				Total =	300.57

1. Adjusted flow is calculated as the product of the gauged flow and the total areas divided by gauged area.
2. Estimated flow is calculated by assuming that flow is approximately 1.7 cfs (0.05 m3/s) per square mile.

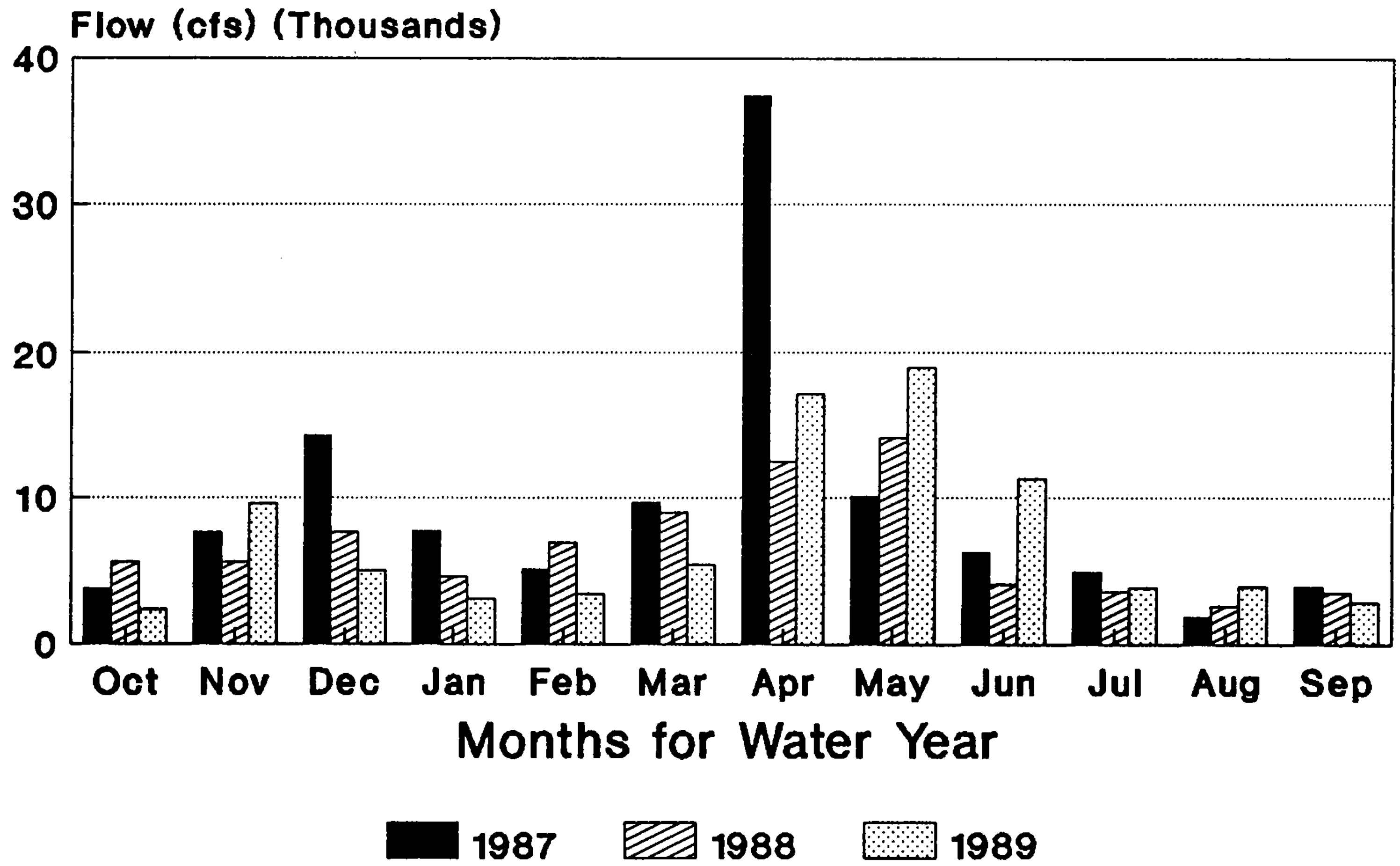
When available, flow data from gauging stations near the mouths of the coastal rivers were used. Otherwise, flow data from other stream gauges within the river drainage basin and nearest the mouth as possible were used. We calculate total flow as:

$$\textbf{Total Flow} = \textbf{Flow at Gauge} \times \frac{\textbf{Total Drainage Area}}{\textbf{Drainage Area Above Gauge}}$$

Most minor coastal rivers which drain to Massachusetts Bays system do not have USGS gauges and many of the major rivers have gauges that capture only part of the total drainage area. Therefore, flows were estimated using another method. Through information provided in the USGS gazetteers, the drainage areas of minor as well as major coastal rivers were estimated by multiplying the conversion factor, 1.7 cfs per square mile, by the river's discharge area. This value was calculated as being typical for such rivers.

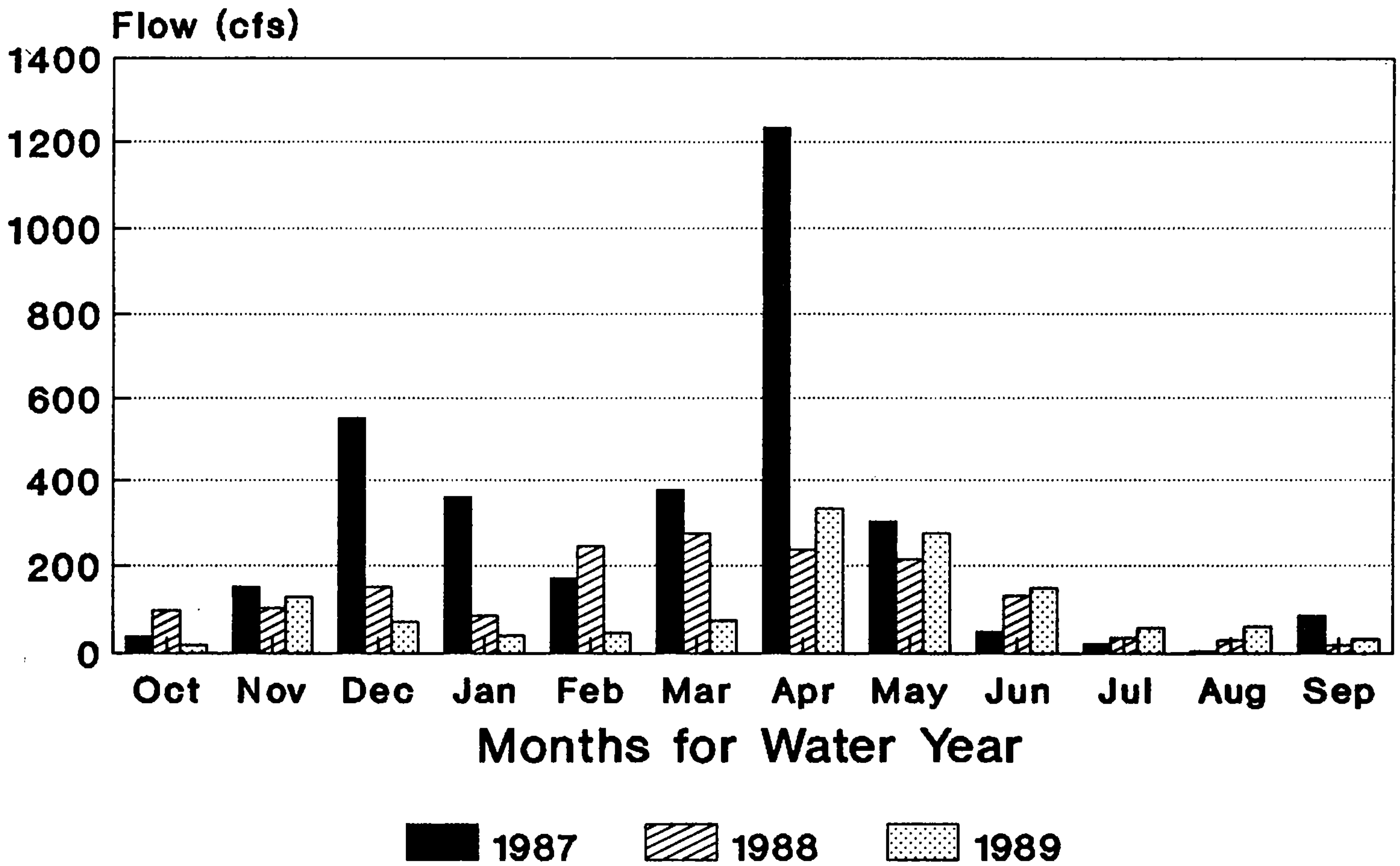
Total estimated average annual freshwater flow to Massachusetts Bays via river discharges is 300 m^3/s including the Merrimack and about 60 m^3/s excluding the Merrimack. Flows from rivers vary seasonally as well as among years. To illustrate recent variability in river flow to the Massachusetts Bays system, monthly mean flow values (cfs) are presented in Figures 5 through 7 for the Merrimack, Ipswich, and Charles Rivers for 1987 to 1989. The overall seasonal pattern of flow was similar for these three rivers. Flow tended to be higher in March through May period and lowest in July through October. Year-to-year variation is clearly evident. For example, the flow in April 1987 is substantially greater than the flows observed in 1988 and 1989.

Figure 5. Seasonal Pattern of Flow
Merrimack River Below Lowell



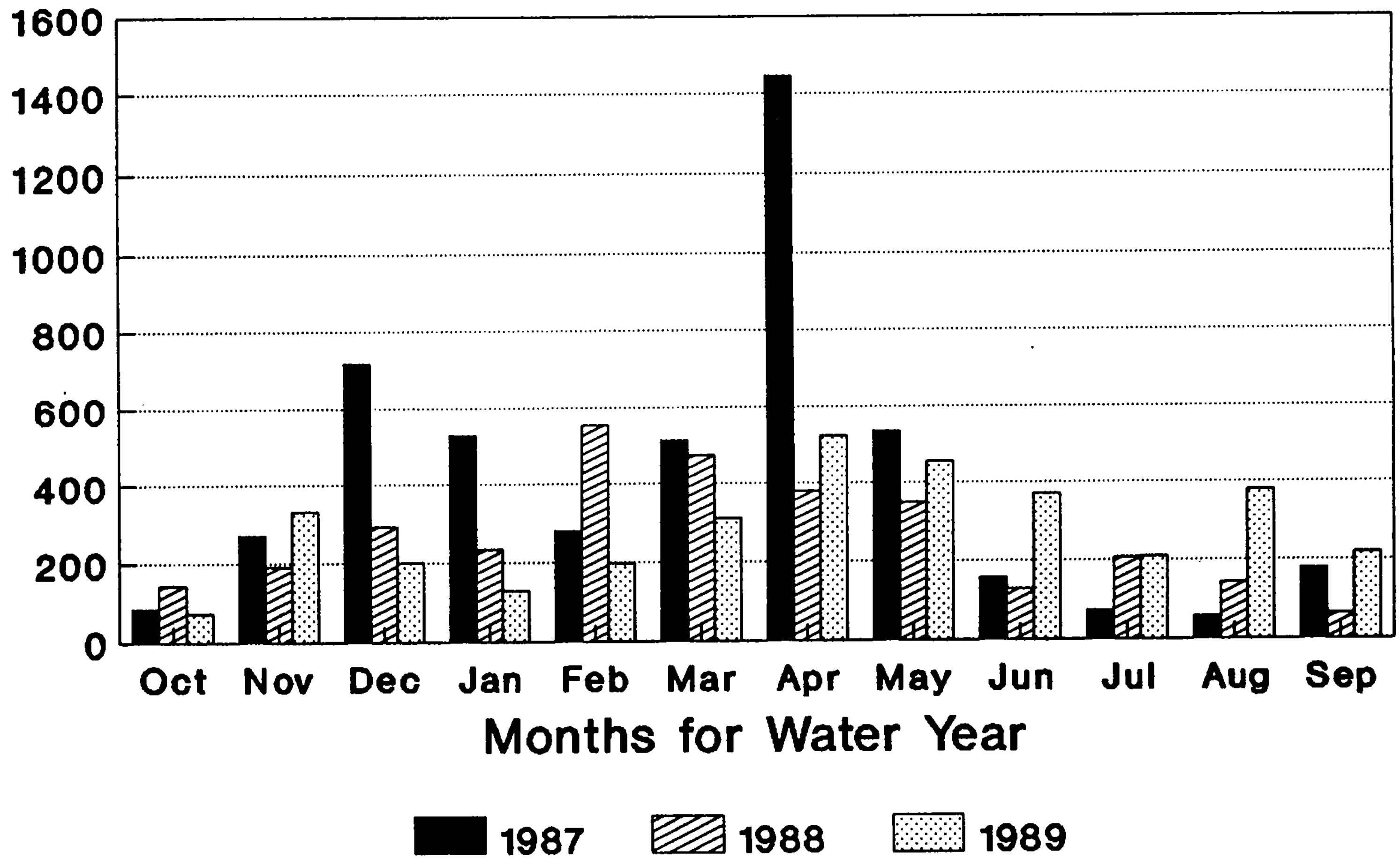
Source: USGS Survey Water-Data Reports

Figure 6. Seasonal Pattern of Flow
Ipswich River at Ipswich



Source: USGS Survey Water-Data Reports

Figure 7. Seasonal Pattern of Flow
Charles River at Waltham



Source: USGS Survey Water-Data Reports

4.0 POINT SOURCE INVENTORY

4.1 General

This section describes the inventory of point source contributions to Massachusetts Bays and the potential loadings of contaminants from these point sources within coastal drainage basins to Massachusetts Bays. Under the Water Quality Act of 1987, point sources are identified as discharges from publicly-owned treatment works (POTWs) and industrial wastewater discharges. Those major point sources which contribute directly to Massachusetts Bays were identified as well as those which contribute to rivers, streams, estuaries or near coastal environments which enter or exchange with the Massachusetts Bays system.

Estimates of loadings are provided for individual dischargers as well as the five major drainage areas.

Estimates of point source contribution to Massachusetts Bays were made by:

- Indentifying and characterizing the point sources within each watershed. Emphasis was placed upon obtaining information on the compounds and biological agents that are the subject of the analysis. However, other parameters monitored for thes effluemts were characterized when available.

- Providing qualitative characterization and, where possible, quantitative estimates of the contaminant contributions from these sources.

- Estimating (by extrapolation from other similar discharges) the concentrations and loadings for sources for which data may be lacking.

4.2 Identification of Point Sources

All major point source discharges within the five drainage basins were identified and located on USGS maps. The locations of the major point source dischargers are shown in Figure 8. Annotated USGS maps are being provided separately to CZM. Major NPDES outfalls which discharge to tributaries of the major coastal rivers are not displayed on Figure 8. These tributaries include Mill Brook, Concord River, Assabet River, Sudbury River, Hop River, French Stream and River Meadow River. The names of the dischargers depicted by number in Figure 8 are provided in Table 4.

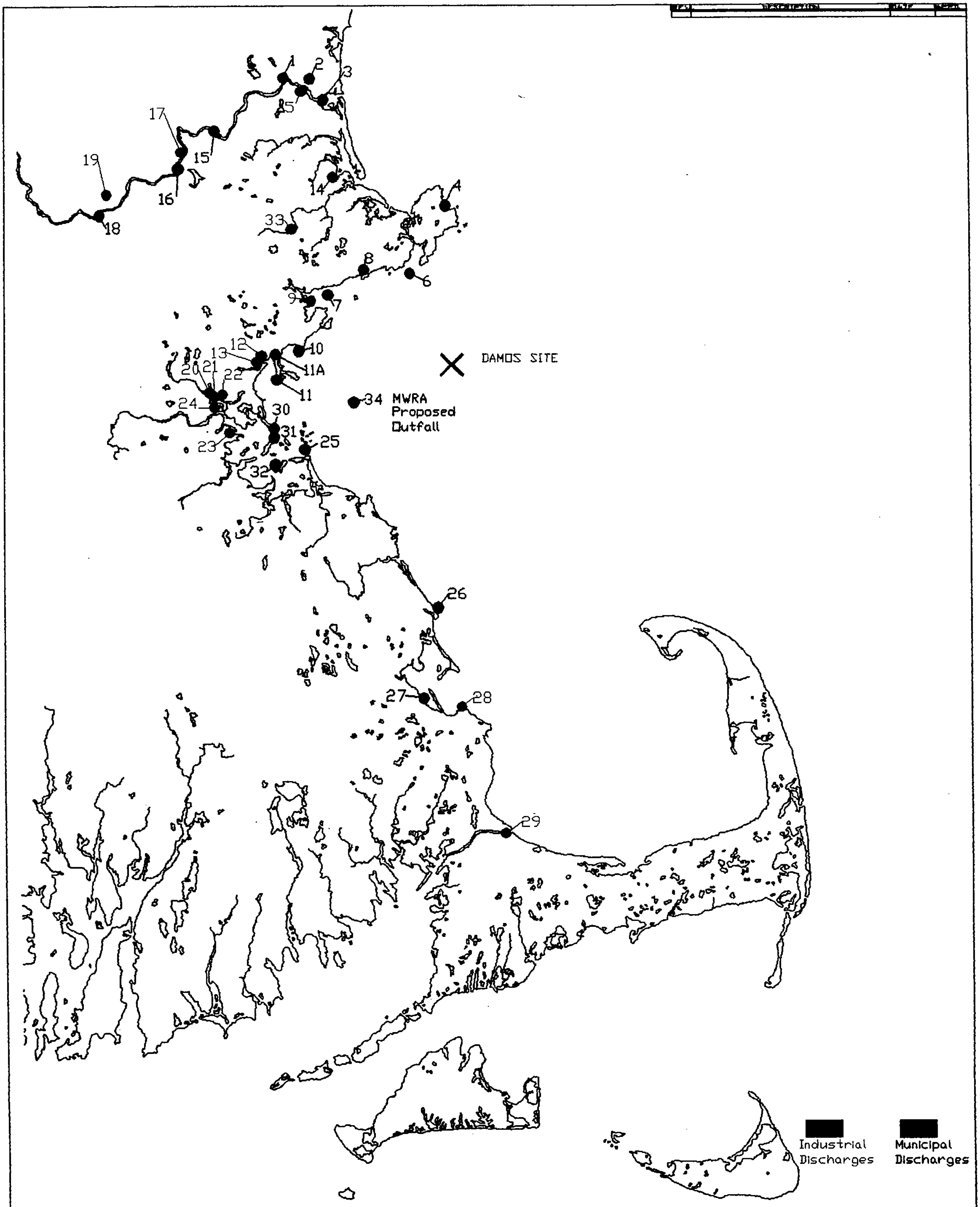


FIGURE 8

Drawn: Cad Concepts	Date:	Menzie * Cura & Associates, Inc.	
Checked: Gary Donahue	Date:	Title: NPDES MAJOR DISCHARGES	
Proj.Eng:	Date:	Size	Document Number 0000
Appd:	Date:	Date: February 7, 1991 Sheet ___ of ___	

Table 4. Names of NPDES permit holders depicted by number in Figure 8.

MAP-ID.	NPDES-#	Facility Name
1	101745	AMESBURY
2	102873	SALISBURY
3	101427	NEWBURYPORT
4	100145	ROCKPORT MTP
5	281	GOULD INC.
6	100625	GLOUCESTER
7	100501	SOUTH ESSEX SEWAGE DIST.
8	100871	MANCHESTER WTP
9	5096	NEW ENGLAND POWER
10	101907	SWAMPSCOTT
11	100552	LYNN SEWER MAIN OUTFALL
11A	100552	LYNN SEWER MAIN 2ND OUTFALL
12	3905	GENERAL ELECTRIC-A.F. PLT 29
13	28193	REFUSE ENERGY SYSTEMS CO.
14	100609	IPSWICH
15	101621	HAVERHILL WPAF
16	100447	GREATER LAWRENCE SD
17	1261	AT&T NORTH ANDOVER
18	100633	LOWELL MSS
19	2225	EXXON(*)
20	809	MONSANTO EVERETT PLANT
21	4740	BOSTON EDISON MYSTIC STATION
22	833	EXXON OIL ISLAND END
23	4731	BOSTON EDISON CO.-NEW BOSTON STATION
24	101192	BOSTON WATER & SEWER COMMISSION(*)
25	4898	CAMBRIDGE ELEC.-KENDALL SQ.
26	101231	HULL
27	101737	MARSHFIELD
28	100587	PLYMOUTH
29	3557	BOSTON EDISON PYLGRIM PLANT
30	4928	CANAL ELECTRIC PLANT-1
31	102351	MWRA DEER ISLAND OUTFALL
32	102351	MWRA SLUDGE OUTFALL
33	102352	MWRA NUT ISLAND OUTFALL
34	281	BOSTIC CHEMICAL GROUP
35	?	MWRA "PROPOSED" OUTFALL

(*)= REFER TO TEXT

RED = INDUSTRIAL DISCHARGERS
BLUE= MUNICIPAL; DISCHARGERS

Point source discharges include NPDES-permitted outfalls. The NPDES permits include industrial as well as municipal facilities. Wastewater discharges to all surface waters in the Commonwealth are regulated by permits which co-issued by EPA and DEP. This system sets levels of effluent quality to be maintained by the POTWs and the industrial dischargers and designates implementation schedules for meeting effluent limits for discharges that contribute to water quality standards violations. NPDES permits are usually reviewed and reissued every five years.

NPDES facilities are either designated as major or minor dischargers. The major NPDES facilities are closely monitored by the regulatory agencies. The discharges from the major facilities must meet more effluent limits than the discharges from the minor NPDES facilities.

There are several factors that determine whether a facility should be listed as a major or minor NPDES discharger.

If a facility is a steam electric power plant with a power output of 500 MW or greater (not using a cooling pond or lake) and/or has a cooling water discharge greater than 25% of the receiving water body's seven-day, ten-year mean low-flow rate, then the facility is automatically listed as a major NPDES discharger. When the facility does not fall under this category, then a series of parameters must be evaluated for the facility. For instance, the NPDES regulatory permit writers take into account the quantity and type of wastewater discharge from the facility. The permit writer scores the facility for not only the quantity and type of wastewater discharged, but also its relationship to the receiving stream low flow. The wastewater type is determined based on the relative volumes of noncontact cooling water, process wastewater (resulting from most manufacturing processes, contact cooling water, and contaminated surface water run-off), and other wastewaters in the total combined discharge from the facility.

The SIC code or codes of a facility is another parameter which must be evaluated by the NPDES permit writer. The SIC code represents the activity at the facility and indicates the toxic pollutant potential of its discharges. For example, a large metal finishing plant which discharges a large quantity of process wastewater could be potentially discharging toxic concentrations of metals into a river.

Once a NPDES facility has been assigned a major or minor designation, then its permit information is included in the Permit Compliance System (PCS) computer data base.

In support of the current project, the EPA Region I Resource Information Center conducted two kinds of computer searches and provided summarized data to Menzie-Cura for each Massachusetts major NPDES discharger within the selected drainage areas. The resultant reports included:

- An Effluent Statistical Summary Report, which summarizes effluent data on an annual basis for 1988, 1989, and 1990;
- A Facility Information Report, which provides general information on the facility (discharger).

These data were used to estimate loadings and to map the locations of the major outfalls. For some discharges, telephone calls were made to local communities to determine the approximate locations of the outfalls.

4.3 Point Source Loadings

4.3.1 Data Sources

Estimates of loadings were made for major point source dischargers using the following data sources:

Computer searches conducted by EPA Region I;
NPDES permit applications;
Discharge Monitoring Reports (DMRs);
301(h) studies;
Massachusetts Division of Water Pollution Control
survey reports.

The DMRs were used as the primary source of information on discharge flow and on the concentrations of pollutants. However, NPDES dischargers are required to monitor for a limited number of parameters and, thus, there are data gaps in the available information. Table 5 provides a summary of which compounds are monitored at each of the effluents. Often the data did not include toxic components, but only conventional pollutants. We extracted and tabulated the available effluent monitoring data from the DMRs for all existing point sources.

Table 5. Compounds monitored for in major NPDES effluents: DMRs.

	TSS	BOD	Nitrogen	Oil & Grease	VOCs	PAHs	PCBs	Phthalates
Merrimack River Drainage Basin								
Westborough WTP 001A	X	X	X		X	PAHs, PCBs & Phthalates		
Billerica-Letchworth WTP FACA	X	X	X			are not routinely measured		
Marlborough STP	X	X				as part of the NPDES monitoring		
Hudson WWTF FACA	X	X	X		X	for major facilities		
Marlborough Westerly WTF 001A	X	X	X		X	in the drainage basin.		
Maynard STP 001A	X	X	X		X			
Raytheon Corporation 001A	X		X			Some data are available for a few		
Concord 001A	X	X	X		X	facilities. In particular,		
Silicon Transistor 001A	X		X	X	X	data are available for		
Raytheon Co.-Wayland 001A	X			X		MWRA effluents.		
NYES Japenamelac WWTP 001A	X		X	X	X			
Amesbury 001A		X	X		X			
Haverhill WPAF 046B	X	X	X		X			
AT&T 001A	X	X	X	X				
Gould Inc. FACA					X			
Greater Lawrence SD 001A	X	X	X	X	X			
Newburyport WPCF 001A	X		X					
Salisbury Sewer Comm. 001A	X	X	X					
Exxon Company 001A	X				X			
Lowell MSS 035A	X	X	X		X			
Very Fine Inc. 0011	X	X	X	X	X			
North Shore Drainage Basin								
Bostic Chemical Group 001A	X	X	X	X	X			
Rockport MTP	X	X		X				
Ipswich Public	X	X	X					
South Essex SD outfall 001A	X	X	X	X	X			
New England Power outfall 001A	X	X		X	X			
Gloucester 001A	X	X	X	X				
Lynn Water & Sewer 002A	X	X		X	X			
Manchester WTP FACA	X	X	X					
Swampscott WPCP 001A	X	X						
General Electric 032A	X			X				
Refuse Energy Systems 001A	X							

	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Tin	Zinc
Merrimack River Drainage Basin								
Westborough WTP 001A			X					X
Billerica-Letchworth WTP FACA		X		X				X
Marlborough STP			X					
Hudson WWTF FACA			X					
Marlborough Westerly WTF 001A		X	X			X		
Maynard STP 001A			X	X				X
Raytheon Corporation 001A							X	X
Concord 001A			X					X
Silicon Transistor 001A			X	X				X
Raytheon Co.-Wayland 001A		X	X	X			X	X
NYES Japenamelac WWTP 001A		X	X					X
Amesbury 001A		X	X	X		X		X
Haverhill WPAF 046B			X					X
AT&T 001A	X	X	X	X	X	X		X
Gould Inc. FACA							X	
Greater Lawrence SD 001A		X	X	X	X	X		X
Newburyport WPCF 001A	X	X	X	X		X	X	X
Salisbury Sewer Comm. 001A								
Exxon Company 001A								
Lowell MSS 035A	X	X	X	X	X	X		X
Very Fine Inc. 0011			X	X	X			X
North Shore Drainage Basin								
Bostic Chemical Group 001A								
Rockport MTP								
Ipswich Public								
South Essex SD outfall 001A			X	X		X		X
New England Power outfall 001A		X	X			X		X
Gloucester 001A			X					X
Lynn Water & Sewer 002A								
Manchester WTP FACA		X	X	X		X		X
Swampscott WPCP 001A								
General Electric 032A								
Refuse Energy Systems 001A								

	TSS	BOD	Nitrogen	Oil & Grease	VOCs	PAHs	PCBs	Phthalates
Boston Harbor Drainage Basin								
MWRA - Deer Island	X	X	X	X	X			
MWRA - Nut Island	X	X	X	X	X			
MWRA - Nut Island Sludge Outfall	X	X	X	X	X			
Boston Edison (Boston) 011A								
Monsanto 002A			X					
Exxon Oil * Island End Terminal	X		X					
Boston Edison (Everett) 008A	X		X					
Cambridge Electric 003A								
Norfolk-Walpole 001A	X		X					
Charles River PCD 011	X		X					
Medfield WWTP 001A	X							
Neponset River								
Plymouth Rubber Co.								
Foxboro Co. Neponset 001B	X		X					
South Shore Drainage Basin								
Hull WTP 001A	X	X	X	X	X			
Plymouth 001A	X	X						
Marshfield WTP 001A								
Boston Edison-Pilgrim Pl.0011A								
Rockland WTP 001C	X	X	X					
Cape Cod Drainage Basin								
Canal Electric-Pl.#1 001A	X							

	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Tin	Zinc
Boston Harbor Drainage Basin								
MWRA - Deer Island	X	X	X	X	X	X		X
MWRA - Nut Island	X	X	X	X	X	X		X
MWRA - Nut Island Sludge Outfall	X	X	X	X	X	X		X
Boston Edison (Boston) 011A			X			X		X
Monsanto 002A								X
Exxon Oil * Island End Terminal								
Boston Edison (Everett) 006A		X	X	X		X		X
Cambridge Electric 003A								
Norfolk-Walpole 001A								
Charles River PCD 011								
Medfield WWTP 001A								
Neponset River								
Plymouth Rubber Co.								
Foxboro Co. Neponset 001B	X	X		X		X		
South Shore Drainage Basin								
Hull WTP 001A			X					X
Plymouth 001A								
Marshfield WTP 001A								
Boston Edison-Pilgrim Pl.0011A								
Rockland WTP 001C								
Cape Cod Drainage Basin								
Canal Electric-Pl.#1 001A			X					

Over the last ten years, the Massachusetts Division of Water Pollution Control (DWPC) has obtained wastewater discharge data for streams and rivers. Additional monitoring data was available for 1983 to 1990 for some NPDES outfalls depending how often the drainage basin was surveyed.

The wastewater discharge data are presented in survey reports for designated river basins. Often these reports include data on the effluent discharge characteristics of the industrial and municipal discharges in that particular river basin. Typically, the DWPC data are from grab samples taken at various outfalls within a particular river basin. DWPC also periodically analyzes wastewater discharges for contaminants that are not specified in the NPDES outfall's permit in addition to typically monitored pollutants.

MWRA provided combined loadings associated with MWRA effluents and sludge for their Nut Island and Deer Island plants. The contribution of each of the facilities was estimated to be 70% from Deer Island and 30% from Nut Island. MWRA data are from Menzie-Cura (1991), the MWRA Facilities Plan for Secondary Treatment, and the Metcalf and Eddy (1990) pilot treatment study.

The major sources of data for POTWs besides the DMRs or obtained directly from MWRA are 301(h) waiver applications. These applications, maintained on file at the EPA Region I Library, provide detailed characterizations of the effluent characteristics from the plant. These documents do not exist for all treatment plants since not all plants have applied for a waiver under the 301(h) program. However, where they do exist, the data have been incorporated into the point source contaminant characterization data base. Several of the major coastal POTWs have developed information on wastewater characteristics as part of 301(h) applications. These include the South Essex Sewage District (SESD) plant. Since the preparation of the SESD 301(h) waiver application in 1986, the mass of pollutants entering the plant has decreased by approximately 50% based on discussion with EPA personnel. This condition has been ascribed to the pretreatment of wastes by industry and by the closing of many of leather tanning businesses in the service territory.

4.3.2 Calculation of NPDES Loadings

Loadings were estimated for the following parameters: biochemical oxygen demand, total phosphorus, total nitrogen, total suspended solids, oil and grease, nonvolatile and volatile organic compounds, polynuclear aromatic hydrocarbons (PAHs), PCBs, phthalate esters, and metals including cadmium, chromium, copper, lead, nickel, and zinc. Total nitrogen was estimated as the sum of total kjeldahl nitrogen, nitrate, and nitrite. Nondetectable concentrations were assumed to be zero.

In PCS effluent summary reports, loads were often cited in kg/day for BOD, phosphorus, and total suspended solids. If the monitoring reports did not give loads, they were calculated as:

Load = contaminant concentration * annual flow

The annual mean concentration was specified in each NPDES facility's effluent summary report. Depending on the type of permit, the reported mean concentration was either a monthly or weekly average. If the report did not include mean concentration the daily maximum concentration was used if flows were continuous rather than intermittent stormwater. Within the NPDES summary permit reports, annual flow data were usually given for the major outfalls.

Many major NPDES facilities have more than one permitted discharge (outfall). However, some of these outfalls are overflow pipes or stormwater culverts which do not continuously discharge. These outfalls will have variable flow. The current analysis distinguishes between wastewater effluents and intermittent stormwater discharges. The latter are not estimated in this section of the report but are included under nonpoint sources.

The estimated loads from the major NPDES discharges were added together for each of the five coastal drainage areas. The Merrimack River Drainage Area includes the Merrimack River, Mill Brook, Concord River, Sudbury River, River Meadow River and Assabet River. The North Shore Drainage Area includes the Parker River, Ipswich River, Saugus River, Rockport Harbor, Gloucester Harbor, Manchester Harbor, Salem Harbor, Lynn Harbor, and King Harbor, and Nahant Bay. The Boston Harbor Drainage Area includes the Mystic River, Charles River, Neponset River, and Weymouth & Weir Rivers. The South Shore Drainage Area includes Plymouth Harbor, North River and Massachusetts Bay. Finally, Cape Cod includes Cape Cod Bay.

The annual loads of a pollutant from a major NPDES discharge were calculated for the years, 1986 to 1990 when flow and concentration data were available. Minimum and maximum loads were determined from the range of annual loads. Often municipal facilities have upgraded the plant and the effects of upgrades can be seen when comparing the annual pollutant loads.

Data were generally lacking in the DMRs of many industrial facilities and POTWs for several compounds that are of interest in this study. Often these compounds are not routinely measured or are reported at below detection limits. The later is the case for many synthetic organics such as PCBs. However, detection limits are frequently high.

In order to estimate loadings of several constituents for which data were sparse, we developed ratios of contaminant loading to the loading of total suspended solids from facilities for which there were data. These estimates were developed for metals and organics which would tend to be associated with solids and which are considered persistent in marine environments. It should be noted that this approach is used only as a means of extrapolation and not all the metals or organics would be associated with the particle fraction. This method was applied to only a few compounds which are viewed as important in the system but for which there was inadequate data: the metals cadmium and lead and the organic compounds PCBs and phthalate esters. These ratios are presented in Table 6. The mean values are used to calculate the loads for POTWs for which data were absent.

Table 6. Contaminant:TSS ratios for selected parameters in sewage effluents of Massachusetts facilities.

Parameter	# Facilities Used in Estimate	Average (kg/kg of TSS)	Minimum (kg/kg of TSS)	Maximum (kg/kg of TSS)
Cadmium	MWRA	2.79E-05	NA	NA
Chromium	8	1.53E-03	1.64E-05	5.9E-03
Lead	7	1.79E-03	1.4E-04	7.6E-03
Mercury	MWRA	<1.77E-03	NA	NA
PCBs	MWRA	< 4.0E-06	NA	NA
Phthalate Esters	MWRA	1.1 E-04	NA	NA

Loads of PAHs via point sources were also estimated from literature values and from recent data for the MWRA effluents (personal communication, M. Connor, MWRA). Data were also available for the MWRA sludge outfall. Although recent, preliminary data indicated that concentrations of PAHs may be even lower, a range of 1 ug/l to 10 ug/l was considered to be representative of the range likely to be found in sewage effluents. This range is used to calculate loads for all POTWs. No data are available for industrial effluents. Those recent, preliminary data indicated that no PAH was present at concentrations above 10 ng/l (personal communication, D. Shea, Battelle). If the individual PAH compounds are present at 10 ng/l, then the total PAH concentration of the effluent would be about 0.1 ug/l rather than 1 ug/l. At levels of 0.1-1.0 ug/l, PAHs in the sludge rather than in effluents dominate the point source loads.

The estimated flows and pollutant loads associated with point sources are presented in Tables 7 through 25.

4.3.3 Minor NPDES Dischargers

Estimates presented in Tables 7 through 26 are for the major point sources in the drainage areas to the Massachusetts Bay. Another group of point sources is the minor NPDES dischargers. This group will contribute to the overall loadings to the drainage areas. However, monitoring data for these minor sources are not entered into PCS and require direct examination of the DMRs. In order to evaluate the potential importance of the minor point sources we conducted an initial examination of the characteristics of these sources.

Table 7. Estimated flows for major dischargers.

Facility	SIC Code	Maximum Flow (m3/s)	Minimum Flow (m3/s)
Merrimack River Drainage			
Concord River			
Westborough WTP 001A	4952	1.95E-01	1.08E-01
Billerica-Letchworth WTP FACA	4952	1.24E-01	1.01E-01
Marlborough STP	4952	1.58E-01	8.32E-02
Hudson WWTF FACA	4952	1.14E-01	7.88E-02
Marlborough Westerly WTF 001A	4952	7.80E-02	6.55E-02
Maynard STP 001A	4952	5.48E-02	4.03E-02
Raytheon Corporation 001A	3672	3.43E-03	1.35E-03
Raytheon Corporation 002A	3672	inactive 12/23/86	
Concord 001A	4952	3.97E-02	8.23E-03
Silicon Transistor 001A	3674	2.93E-02	2.10E-02
Silicon Transistor 002A	3674	1.08E-02	2.00E-03
Silicon Transistor 002B	3674	1.08E-02	2.00E-03
Raytheon Co.-Wayland 001A	3625	1.93E-03	1.32E-03
Raytheon Co.-Wayland 002A	3625		
Raytheon Co.-Wayland 003A	3625	5.62E-04	2.56E-04
Raytheon Co.-Wayland 004A	3625	6.83E-05	1.04E-05
NYES Japenamelac WWTP 001A	3479	1.28E-03	1.31E-04
Merrimack River			
Amesbury 001A	4952	7.62E-02	6.67E-02
Haverhill WPAF 046A	4952	5.59E-01	4.37E-01
Haverhill WPAF 046B	4952	sanitary runoff	
AT&T 001A	3661	3.28E-01	3.89E-02
AT&T 001B	3661	6.96E-02	1.89E-02
AT&T 001C	3661	4.83E-02	3.94E-02
AT&T 001D	3661	8.76E-02	8.54E-02
AT&T 001E	3661		
AT&T 002A	3661	3.13E-03	2.61E-03
Gould Inc. FACA	3613	1.27E-03	9.27E-04
Greater Lawrence SD 001A	4952	1.73E+00	1.58E+00
Newburyport WPCF 001A	4952	1.18E-01	8.47E-02
Salisbury Sewer Comm. 001A	4952	1.50E-02	1.38E-02
Exxon Company 001A	5171		
Exxon Company 002A	5171		
Lowell MSS 035A	4952	1.31E+00	6.61E-01
Very Fine Inc. 001A	2033	2.47E-03	1.72E-03
Very Fine Inc. 001B	2033	6.92E-03	2.77E-03
Very Fine Inc. 001C	2033	4.64E-03	3.42E-03
Very Fine Inc. 001D	2033	6.26E-03	3.98E-03
Very Fine Inc. 001E	2033	noncontact cooling water	
Very Fine Inc. 0011	2033	2.77E-02	1.27E-02

Facility	SIC Code	Maximum Flow (m3/s)	Minimum Flow (m3/s)
North Shore Drainage Basin			
Ipswich River			
Bostic Chemical Group 001A	2821	2.54E-02	1.05E-03
Bostic Chemical Group 0010	2821	6.22E-02	8.76E-03
Bostic Chemical Group 003A	2821	7.10E-04	1.97E-04
Bostic Chemical Group 003B	2821		
Bostic Chemical Group 004A	2821	3.15E-03	1.18E-03
Bostic Chemical Group 004B	2821		
Bostic Chemical Group 005A	2821	2.53E-03	4.82E-04
Rockport MTP	4952	2.79E-02	2.41E-02
Ipswich Public	4952	6.41E-02	3.03E-02
North Shore			
South Essex SD outfall 001A	4952	1.19E+00	9.15E-01
New England Power outfall 001A	4911	1.87E+01	1.75E+01
New England Power outfall 005A	4911		
New England Power outfall 006B	4911	9.19E-03	4.49E-04
New England Power outfall 007A	4911		
New England Power outfall 008A	4911	1.31E-03	1.31E-03
New England Power outfall 010A	4911	1.31E-03	1.31E-03
New England Power outfall 014A	4911		
Gloucester 001A	4952	1.61E-01	1.10E-01
Lynn Water & Sewer 001A	4952	3.68E+00	1.25E+00
Lynn Water & Sewer 002A	4952	4.17E-02	2.63E-04
Manchester WTP FACA	4952	3.00E-02	1.76E-02
Swampscott WPCP FACA	4952	4.16E-02	4.16E-02
Swampscott WPCP 001A	4952	1.26E-01	3.72E-02
General Electric 001A	3511	4.38E-04	2.92E-04
General Electric 003A	3511	3.50E-02	2.33E-02
General Electric 005A	3511	8.76E-04	5.84E-04
General Electric 007A	3511	4.91E-02	3.27E-02
General Electric 009A	3511	3.11E-03	2.07E-03
General Electric 010A	3511	1.58E-01	1.05E-01
General Electric 012A	3511		
General Electric 013A	3511	1.53E-02	1.02E-02
General Electric 014A	3511	1.10E+00	6.84E-01
General Electric 015A	3511	1.10E-03	7.30E-04
General Electric 017A	3511	2.19E-04	1.46E-04
General Electric 018A	3511	1.10E+00	7.30E-01
General Electric 019A	3511	1.53E-02	1.02E-02
General Electric 020A	3511	7.36E-01	2.96E-01
General Electric 021A	3511	1.58E-01	1.05E-01
General Electric 027A	3511	4.38E-02	2.92E-02
General Electric 028A	3511	3.29E-03	2.19E-03
General Electric 029A	3511	9.46E-01	9.46E-02
General Electric 030A	3511	2.19E-03	2.19E-03
General Electric 031A	3511	3.90E-02	3.90E-02
Refuse Energy Systems 001A	4923	2.37E+00	2.37E+00

Facility	SIC Code	Maximum Flow (m3/s)	Minimum Flow (m3/s)
Boston Harbor Drainage Basin			
Boston Harbor			
MWRA - Deer Island	4952	1.40E+01	1.40E+01
MWRA - Nut Island	4952	6.00E+00	6.00E+00
MWRA - Nut Island Sludge Outfall	4952		
Mystic River			
Boston Edison (Boston) 011A	4911	1.58E-02	6.57E-03
Boston Edison (Boston) 012A	4911		
Boston Edison (Boston) 013A	4911		
Boston Edison (Boston) 014A	4911		
Monsanto 001A	2819	8.76E-03	2.92E-03
Exxon Oil * Island End Terminal	5172	2.71E-02	3.69E-04
Boston Edison (Everett) 002A	4911	2.41E-02	1.26E-02
Boston Edison (Everett) 003A	4911	1.75E-02	1.75E-02
Cambridge Electric 001A	4911	2.11E+00	1.91E+00
Cambridge Electric 002A	4911	2.11E+00	1.91E+00
Cambridge Electric 003A	4911	2.81E-01	1.02E-01
Charles River			
Norfolk-Walpole 001A	9223	1.37E-02	1.34E-02
Norfolk-Walpole 001B	9223	1.39E-02	1.39E-02
Charles River PCD 011	4952	1.68E-01	1.14E-01
Charles River PCD 012	4952	1.60E-01	1.60E-01
Charles River PCD 013	4952	1.48E-01	1.48E-01
Charles River PCD 014	4952	1.17E-01	1.17E-01
Medfield WWTP FACA	4952	3.33E-02	3.33E-02
Medfield WWTP 001A	4952	4.00E-02	3.57E-02
Neponset River			
Plymouth Rubber Co.	2821	2.01E-01	1.31E-01
Foxboro Co. Neponset 001A	3471	2.88E-03	2.88E-03
Foxboro Co. Neponset 001B	3471	3.23E-03	4.04E-04
South Shore Drainage Basin			
Hull WTP 001A	4952	6.57E-02	5.61E-02
Plymouth 001A	4952	1.10E-01	1.02E-01
Marshfield WTP 001A	4952	4.24E-02	4.04E-02
Boston Edison-Pilgrim Pl.0011	4911	1.70E+01	7.71E+00
Boston Edison-Pilgrim Pl.0021	4911	1.09E+00	6.13E-02
Boston Edison-Pilgrim Pl.003A	4911	4.42E-02	1.26E-02
Boston Edison-Pilgrim Pl.010A	4911	3.02E-01	1.61E-01
Boston Edison-Pilgrim Pl.0011A	4911	2.48E-05	2.23E-05
Rockland WTP 001C	4952	1.12E-01	6.18E-02
Rockland WTP 001B	4952	1.07E-01	8.51E-02
Cape Cod Drainage Basin			
Canal Electric-Pl.#1 001A	4911	1.52E+01	6.40E+00
Canal Electric-Pl.#1 002A	4911	1.10E-01	1.10E-01
Canal Electric-Pl.#1 011A	4911	6.44E-03	5.39E-03
Canal Electric-Pl.#1 012A	4911	1.88E-03	1.62E-03

Table 8. Estimated point source loadings of solids.

Point Sources Total Suspended Solids	Lower Estimate (kg/yr)	Higher Estimate (kg/yr)
Merrimack River Drainage Basin		
Concord River		
Westborough WTP	1.30E+04	3.90E+04
Billerica-Letchworth WTP FACA	1.30E+04	3.90E+04
Marlborough STP	1.50E+04	4.50E+04
Hudson WWTF FACA	2.60E+04	6.40E+04
Marlborough Westerly WTF	3.20E+04	5.60E+04
Maynard STP	1.80E+04	3.60E+04
Raytheon Corporation	1.80E+01	2.80E+02
Concord	1.30E+03	4.00E+04
Silicon Transistor	4.20E+02	3.40E+03
Raytheon Co.-Wayland	1.80E+02	3.90E+02
NYES Japenamelac WWTP	1.30E+05	6.70E+05
Merrimack River		
Amesbury		
Haverhill WPAF	2.90E+04	3.60E+05
AT&T	7.70E+03	8.10E+03
Gould Inc. FACA		
Greater Lawrence SD	3.40E+05	7.10E+05
Newburyport WPCF	1.20E+04	3.10E+04
Salisbury Sewer Comm.	2.30E+02	1.90E+03
Exxon Company	0.00E+00	0.00E+00
Lowell MSS	3.60E+03	3.60E+03
Very Fine Inc.	3.90E+07	4.00E+07
Subtotal	3.96E+07	4.21E+07
North Shore Drainage Basin		
Ipswich River		
Bostic Chemical Group	9.30E+03	9.30E+03
Rockport MTP	2.70E+03	7.80E+03
Ipswich Public	5.10E+03	3.50E+04
North Shore		
South Essex SD	1.00E+06	6.20E+06
New England Power	2.20E+03	2.20E+03
Gloucester	2.30E+05	4.40E+05
Lynn Water & Sewer	2.20E+06	8.30E+06
Manchester WTP FACA	9.40E+03	3.80E+04
Swampscott WPCP	1.10E+05	3.80E+05
General Electric	0.00E+00	0.00E+00
Refuse Energy Systems	0.00E+00	0.00E+00
Subtotal	3.57E+06	1.54E+07

Point Sources **Total Suspended Solids**	**Lower Estimate (kg/yr)**	**Higher Estimate (kg/yr)**
Boston Harbor Drainage Basin		
Boston Harbor		
MWRA - Deer Island	4.30E+07	4.30E+07
MWRA - Nut Island	1.90E+07	1.90E+07
MWRA - Nut Island Sludge Outfall	2.30E+07	2.30E+07
Mystic River		
Boston Edison (Boston)		
Monsanto		
Exxon Oil * Island End Terminal	3.50E+02	1.90E+04
Boston Edison (Everett)	1.70E+04	5.70E+04
Cambridge Electric		
Charles River		
Norfolk-Walpole	4.70E+03	5.90E+03
Charles River PCD	2.00E+06	3.10E+06
Medfield WWTP	8.00E+03	1.00E+04
Neponset River		
Plymouth Rubber Co.		
Foxboro Co. Neponset	3.10E+03	3.10E+01
Subtotal	8.70E+07	8.82E+07
South Shore Drainage Basin		
Hull WTP	2.20E+04	1.30E+05
Plymouth	8.60E+04	1.20E+05
Marshfield WTP		
Boston Edison-Pilgrim Pl.		
Rockland WTP	3.60E+04	3.60E+04
Subtotal	1.44E+05	2.86E+05
Cape Cod Drainage Basin		
Canal Electric-Pl.	5.60E+03	6.60E+03
Subtotal	5.60E+03	6.60E+03
TOTAL	1.30E+08	1.46E+08

Table 9. Estimated point source loadings of biochemical oxygen demand (kg/yr).

Biochemical Oxygen Demand	Lower Estimate	Higher Estimate
Merrimack River Drainage Basin		
Concord River		
Westborough WTP	1.20E+04	3.40E+04
Billerica-Letchworth WTP FACA	3.90E+04	2.30E+05
Marlborough STP	4.70E+03	3.00E+04
Hudson WWTF FACA	4.00E+04	7.10E+04
Marlborough Westerly WTF	2.30E+04	4.50E+04
Maynard STP	2.50E+04	7.30E+04
Raytheon Corporation		
Concord	3.30E+03	2.80E+04
Silicon Transistor		
Raytheon Co.-Wayland		
NYES Japenamelac WWTP		
Merrimack River		
Amesbury	1.00E+05	1.00E+05
Haverhill WPAF	2.20E+05	7.30E+05
AT&T	4.60E+04	5.90E+04
Gould Inc. FACA		
Greater Lawrence SD	3.40E+05	1.10E+06
Newburyport WPCF		
Salisbury Sewer Comm.	9.30E+02	1.10E+03
Exxon Company		
Lowell MSS	2.40E+05	7.20E+05
Very Fine Inc.	9.00E+03	2.00E+04
Subtotal	1.10E+06	3.24E+06
North Shore Drainage Basin		
Ipswich River		
Bostic Chemical Group	2.30E+03	2.30E+03
Rockport MTP	8.40E+03	1.00E+04
Ipswich Public	1.20E+04	3.00E+04
North Shore		
South Essex SD	2.30E+07	2.00E+07
New England Power	7.20E+01	7.20E+01
Gloucester	7.50E+05	7.50E+05
Lynn Water & Sewer	5.30E+06	1.40E+07
Manchester WTP FACA	1.30E+04	4.60E+04
Swampscott WPCP	8.60E+06	3.50E+07
General Electric		
Refuse Energy Systems		
Subtotal	3.77E+07	6.98E+07

Biochemical Oxygen Demand	Lower Estimate	Higher Estimate
Boston Harbor Drainage Basin		
Boston Harbor		
MWRA - Deer Island	5.40E+07	5.40E+07
MWRA - Nut Island	2.20E+07	2.20E+07
MWRA - Nut Island Sludge Outfall	1.50E+07	1.50E+07
Mystic River		
Boston Edison (Boston)		
Monsanto		
Exxon Oil * Island End Terminal		
Boston Edison (Everett)		
Cambridge Electric		
Charles River		
Norfolk-Walpole		
Charles River PCD		
Medfield WWTP		
Neponset River		
Plymouth Rubber Co.		
Foxboro Co. Neponset		
Subtotal	9.10E+07	9.10E+07
South Shore Drainage Basin		
Hull WTP	2.50E+04	3.80E+04
Plymouth	7.60E+04	1.00E+05
Marshfield WTP		
Boston Edison-Pilgrim Pl.		
Rockland WTP	2.40E+04	6.00E+04
Subtotal	1.25E+05	1.98E+05
Cape Cod Drainage Basin		
Canal Electric-Pl.		
Subtotal	0.00E+00	0.00E+00
TOTAL	1.30E+08	1.64E+08

Table 10. Estimated point source loadings of nitrogen.

Point Sources Nitrogen	Lower Estimate (kg/yr)	Higher Estimate (kg/yr)
Merrimack River Drainage Basin		
Concord River		
Westborough WTP	1.70E+03	8.40E+04
Billerica-Letchworth WTP FACA	1.40E+05	1.40E+05
Marlborough STP		
Hudson WWTF FACA	5.90E+02	7.50E+04
Marlborough Westerly WTF	8.30E+04	8.30E+04
Maynard STP	8.10E+04	8.10E+04
Raytheon Corporation	2.50E+02	6.40E+02
Concord	7.10E+03	4.00E+04
Silicon Transistor	2.10E+03	7.90E+04
Raytheon Co.-Wayland		
NYES Japenamelac WWTP	3.20E+05	6.00E+05
Merrimack River		
Amesbury	4.30E+04	4.30E+04
Haverhill WPAF	1.20E+05	1.20E+05
AT&T	2.50E+04	3.70E+04
Gould Inc. FACA		
Greater Lawrence SD	7.80E+05	8.70E+05
Newburyport WPCF	5.20E+04	5.20E+04
Salisbury Sewer Comm.	1.50E+03	2.90E+03
Exxon Company		
Lowell MSS	4.20E+05	4.60E+05
Very Fine Inc.	1.10E+00	8.40E+01
Subtotal	2.08E+06	2.77E+06
North Shore Drainage Basin		
Ipswich River		
Bostic Chemical Group	1.10E+03	1.10E+03
Rockport MTP		
Ipswich Public	3.90E+04	3.90E+04
North Shore		
South Essex SD	3.90E+06	3.90E+06
New England Power		
Gloucester	1.40E+05	1.40E+05
Lynn Water & Sewer		
Manchester WTP FACA	1.20E+04	1.20E+04
Swampscott WPCP		
General Electric		
Refuse Energy Systems		
Subtotal	4.09E+06	4.09E+06

Point Sources Nitrogen	Lower Estimate (kg/yr)	Higher Estimate (kg/yr)
Boston Harbor Drainage Basin		
Boston Harbor		
MWRA - Deer Island	7.00E+06	7.00E+06
MWRA - Nut Island	3.30E+06	3.30E+06
MWRA - Nut Island Sludge Outfall	1.10E+06	1.10E+06
Mystic River		
Boston Edison (Boston)		
Monsanto	3.20E+02	3.20E+02
Exxon Oil * Island End Terminal	5.60E+03	5.60E+03
Boston Edison (Everett)	4.80E+03	4.80E+03
Cambridge Electric		
Charles River		
Norfolk-Walpole	5.80E+04	6.50E+04
Charles River PCD	1.20E+04	3.10E+04
Medfield WWTP		
Neponset River		
Plymouth Rubber Co.		
Foxboro Co. Neponset	3.90E+04	3.90E+04
Subtotal	1.15E+07	1.15E+07
South Shore Drainage Basin		
Hull WTP	7.90E+04	7.90E+04
Plymouth		
Marshfield WTP		
Boston Edison-Pilgrim Pl.		
Rockland WTP	1.20E+03	5.20E+03
Subtotal	8.02E+04	8.42E+04
Cape Cod Drainage Basin		
Canal Electric-Pl.		
Subtotal		
TOTAL	1.78E+07	1.85E+07

Table 11. Estimated point source loadings of phosphorus.

Point Sources Phosphorus	Lower Estimate (kg/yr)	Higher Estimate (kg/yr)
Merrimack River Drainage Basin		
Concord River		
Westborough WTP	2.15E+04	2.15E+04
Billerica-Letchworth WTP FACA	1.82E+04	1.82E+04
Marlborough STP	4.78E+04	4.78E+04
Hudson WWTF FACA	1.61E+04	1.61E+04
Marlborough Westerly WTF	2.75E+04	2.75E+04
Maynard STP	1.11E+04	1.11E+04
Raytheon Corporation		
Concord	2.04E+03	7.43E+03
Silicon Transistor	2.40E+02	2.40E+02
Raytheon Co.-Wayland	3.07E+02	3.07E+02
NYES Japenamelac WWTP		
Merrimack River		
Amesbury	1.69E+04	1.69E+04
Haverhill WPAF	1.17E+04	1.17E+04
AT&T	1.38E+03	2.36E+03
Gould Inc. FACA		
Greater Lawrence SD	6.23E+04	9.32E+04
Newburyport WPCF	7.56E+03	7.56E+03
Salisbury Sewer Comm.		
Exxon Company		
Lowell MSS		
Very Fine Inc.		
Subtotal	2.45E+05	2.82E+05
North Shore Drainage Basin		
Ipswich River		
Bostic Chemical Group		
Rockport MTP		
Ipswich Public		
North Shore		
South Essex SD	2.93E+05	2.93E+05
New England Power		
Gloucester	1.53E+04	1.53E+04
Lynn Water & Sewer		
Manchester WTP FACA	1.63E+03	1.63E+03
Swampscott WPCP		
General Electric		
Refuse Energy Systems		
Subtotal	3.10E+05	3.10E+05

Point Sources Phosphorus	Lower Estimate (kg/yr)	Higher Estimate (kg/yr)
Boston Harbor Drainage Basin		
Boston Harbor		
MWRA - Deer Island	1.75E+06	1.75E+06
MWRA - Nut Island	7.50E+05	7.50E+05
MWRA - Nut Island Sludge Outfall	7.00E+04	7.00E+04
Mystic River		
Boston Edison (Boston)		
Monsanto		
Exxon Oil * Island End Terminal		
Boston Edison (Everett)		
Cambridge Electric		
Charles River		
Norfolk-Walpole	3.76E+02	1.18E+03
Charles River PCD	4.58E+03	9.76E+03
Medfield WWTP	5.81E+02	8.65E+02
Neponset River		
Plymouth Rubber Co.		
Foxboro Co. Neponset	9.08E+01	9.08E+01
Subtotal	2.58E+06	2.58E+06
South Shore Drainage Basin		
Hull WTP	1.14E+04	1.14E+04
Plymouth		
Marshfield WTP		
Boston Edison-Pilgrim Pl.		
Rockland WTP	1.41E+00	2.00E+00
Subtotal	1.14E+04	1.14E+04
Cape Cod Drainage Basin		
Canal Electric-Pl.		
Subtotal		
TOTAL	3.14E+06	3.19E+06

Table 12. Estimated point source loadings of oil and grease.

Point Sources Oil and Grease	Lower Estimate (kg/yr)	Higher Estimate (kg/yr)
Merrimack River Drainage Basin		
Concord River	NOTE: THIS TABLE NEEDS A QA CHECK	
Westborough WTP		
Billerica-Letchworth WTP FACA		
Marlborough STP		
Hudson WWTF FACA		
Marlborough Westerly WTF		
Maynard STP		
Raytheon Corporation		
Concord		
Silicon Transistor	1.27E+03	7.36E+03
Raytheon Co.-Wayland	2.56E+01	2.67E+02
NYES Japenamelac WWTP	1.72E+01	1.24E+02
Merrimack River		
Amesbury		
Haverhill WPAF		
AT&T	4.59E+04	5.98E+04
Gould Inc. FACA		
Greater Lawrence SD	2.97E+02	3.09E+02
Newburyport WPCF		
Salisbury Sewer Comm.		
Exxon Company		
Lowell MSS		
Very Fine Inc.	3.30E+02	1.81E+03
Subtotal	4.79E+04	6.97E+04
North Shore Drainage Basin		
Ipswich River		
Bostic Chemical Group	1.20E+03	7.37E+03
Rockport MTP	1.20E+03	7.37E+03
Ipswich Public		
North Shore		
South Essex SD	5.95E+04	8.75E+05
New England Power	6.59E+02	2.27E+03
Gloucester	2.90E+04	2.69E+05
Lynn Water & Sewer	1.12E+06	1.99E+06
Manchester WTP FACA		
Swampscott WPCP		
General Electric	2.60E+04	2.08E+05
Refuse Energy Systems		
Subtotal	1.24E+06	3.36E+06

Point Sources Oil and Grease	Lower Estimate (kg/yr)	Higher Estimate (kg/yr)
Boston Harbor Drainage Basin		
Boston Harbor		
MWRA - Deer Island	1.39E+04	1.39E+04
MWRA - Nut Island	5.95E+03	5.95E+03
MWRA - Nut Island Sludge Outfall		
Mystic River		
Boston Edison (Boston)		
Monsanto	1.23E+02	5.81E+02
Exxon Oil * Island End Terminal	2.83E+01	5.66E+03
Boston Edison (Everett)	9.52E+01	7.35E+02
Cambridge Electric		
Charles River		
Norfolk-Walpole		
Charles River PCD		
Medfield WWTP		
Neponset River		
Plymouth Rubber Co.	9.67E+03	3.36E+04
Foxboro Co. Neponset	1.87E+02	6.68E+02
Subtotal	2.99E+04	6.11E+04
South Shore Drainage Basin		
Hull WTP	8.77E+03	1.17E+04
Plymouth		
Marshfield WTP		
Boston Edison-Pilgrim Pl.		
Rockland WTP		
Subtotal	8.77E+03	1.17E+04
Cape Cod Drainage Basin		
Canal Electric-Pl.		
Subtotal		
TOTAL	1.32E+06	3.50E+06

Table 13. Estimated point source loadings of volatile organic compounds.

Point Sources Volatile Organic Compounds	Lower Estimate	Higher Estimate
Merrimack River Drainage Basin		
Concord River		
Westborough WTP	1.24E+02	1.24E+02
Billerica-Letchworth WTP FACA		
Marlborough STP		
Hudson WWTF FACA	7.03E+00	7.03E+00
Marlborough Westerly WTF	6.51E+01	6.51E+01
Maynard STP	9.84E+00	9.84E+00
Raytheon Corporation		
Concord	8.26E+00	8.26E+00
Silicon Transistor	6.23E+01	7.51E+03
Raytheon Co.-Wayland		
NYES Japenamelac WWTP	1.86E-01	1.86E-01
Merrimack River		
Amesbury	7.34E+01	7.34E+01
Haverhill WPAF	2.35E+03	2.35E+03
AT&T		
Gould Inc. FACA	1.86E-01	1.86E-01
Greater Lawrence SD	1.15E+02	1.15E+02
Newburyport WPCF		
Salisbury Sewer Comm.		
Exxon Company	8.82E+03	8.82E+03
Lowell MSS	1.37E+02	4.03E+02
Very Fine Inc.	7.33E+00	7.45E+03
Subtotal	1.18E+04	2.69E+04
North Shore Drainage Basin		
Ipswich River		
Bostic Chemical Group	1.37E+04	1.37E+04
Rockport MTP		
Ipswich Public		
North Shore		
South Essex SD	4.66E+03	8.79E+06
New England Power	1.14E+00	1.14E+00
Gloucester		
Lynn Water & Sewer	1.14E+00	1.14E+00
Manchester WTP FACA		
Swampscott WPCP		
General Electric		
Refuse Energy Systems		
Subtotal	1.84E+04	8.81E+06

Point Sources Volatile Organic Compounds	Lower Estimate	Higher Estimate
Boston Harbor Drainage Basin		
Boston Harbor		
MWRA - Deer Island (1)	1.53E+05	1.53E+05
MWRA - Nut Island (1)	6.57E+04	6.57E+04
MWRA - Nut Island Sludge Outfall: benzene only	3.00E+00	3.00E+00
Mystic River		
Boston Edison (Boston)		
Monsanto		
Exxon Oil * Island End Terminal		
Boston Edison (Everett)		
Cambridge Electric		
Charles River		
Norfolk-Walpole		
Charles River PCD		
Medfield WWTP		
Neponset River		
Plymouth Rubber Co.		
Foxboro Co. Neponset		
Subtotal	2.19E+05	2.19E+05
South Shore Drainage Basin		
Hull WTP	2.32E+04	2.32E+04
Plymouth		
Marshfield WTP		
Boston Edison-Pilgrim Pl.		
Rockland WTP		
Subtotal	2.32E+04	2.32E+04
Cape Cod Drainage Basin		
Canal Electric-Pl.		
Subtotal		
TOTAL	2.72E+05	9.08E+06

1. VOCs for MWRA efluents are from Table 3.3.1-1 of the Secondary Treatment Facilities Plan Volume V, Appendix A and includes the following: benzene, bromomethane, chloroform, ethylbenzene, methylene chloride, styrene, tetrachloroethylene, trichloroethylene, acetone, 2-butanone, carbon disulfide, chlorobenzene, dichloroethylene, methylpentanone, ,trichloroethane, tetrachloroethane, toluene, and xylenes

Table 14. Estimated point source loadings of polynuclear aromatic hydrocarbons.

Point Sources PAH Loadings	PAH Load Min. Flow at Conc. of (1 ug/l)	PAH Load Max Flow at Conc. of (10 ug/l)
Merrimack River Drainage		
Westborough WTP 001A	3.41E+00	6.15E+01
Billerica-Letchworth WTP FACA	3.18E+00	3.93E+01
Marlborough STP	2.63E+00	4.98E+01
Hudson WWTF FACA	2.49E+00	3.60E+01
Marlborough Westerly WTF 001A	2.07E+00	2.46E+01
Maynard STP 001A	1.27E+00	1.73E+01
Greater Lawrence SD 001A	5.00E+01	5.45E+02
Newburyport WPCF 001A	2.68E+00	3.72E+01
Salisbury Sewer Comm. 001A	4.36E-01	4.75E+00
	6.81E+01	8.16E+02
North Shore Drainage Basin		
Ipswich River		
Rockport MTP	7.61E-01	8.80E+00
Ipswich Public	9.58E-01	2.03E+01
North Shore		
South Essex SD outfall 001A	2.89E+01	3.76E+02
Gloucester 001A	3.48E+00	5.09E+01
Lynn Water & Sewer 001A	3.95E+01	1.16E+03
Lynn Water & Sewer 002A	8.31E-03	1.32E+01
Manchester WTP FACA	5.55E-01	9.49E+00
Swampscott WPCP FACA	1.32E+00	1.32E+01
Swampscott WPCP 001A	1.18E+00	3.97E+01
	7.66E+01	1.70E+03
Boston Harbor Drainage Basin		
Boston Harbor		
MWRA - Deer Island	4.36E+02	4.36E+03
MWRA - Nut Island	1.87E+02	1.87E+03
MWRA - Nut Island Sludge Outfall	4.60E+01	2.16E+03
Charles River		
Medfield WWTP FACA	1.05E+00	1.05E+01
Medfield WWTP 001A	1.13E+00	1.26E+01
	6.71E+02	8.41E+03
South Shore Drainage Basin		
Hull WTP 001A	1.77E+00	2.08E+01
Plymouth 001A	3.21E+00	3.49E+01
Marshfield WTP 001A	1.28E+00	1.34E+01
Rockland WTP 001C	1.95E+00	3.53E+01
Rockland WTP 001B	2.69E+00	3.39E+01
	1.09E+01	1.38E+02
Cape Cod Drainage Basin		
Totals	8.27E+02	1.11E+04

Table 15. Estimated point source loadings of polychlorinated biphenyls (PCBs).

POTW Point Sources PCBs	Lower Estimate (kg/yr)	Higher Estimate (kg/yr)
Merrimack River Drainage Basin		
Concord River		
Westborough WTP	5.20E-02	1.56E-01
Billerica-Letchworth WTP FACA	5.20E-02	1.56E-01
Marlborough STP	6.00E-02	1.80E-01
Hudson WWTF FACA	1.04E-01	2.56E-01
Marlborough Westerly WTF	1.28E-01	2.24E-01
Maynard STP	7.20E-02	1.44E-01
Raytheon Corporation		
Concord	5.20E-03	1.60E-01
Silicon Transistor	1.68E-03	1.36E-02
Raytheon Co.-Wayland	7.20E-04	1.56E-03
NYES Japenamelac WWTP	5.20E-01	2.68E+00
Merrimack River		
Amesbury		
Haverhill WPAF	1.16E-01	1.44E+00
AT&T		
Gould Inc. FACA		
Greater Lawrence SD	4.00E-06	4.00E-06
Newburyport WPCF	4.00E-06	4.00E-06
Salisbury Sewer Comm.	4.00E-06	4.00E-06
Exxon Company		
Lowell MSS		
Very Fine Inc.		
Subtotal	1.11E+00	5.41E+00
North Shore Drainage Basin		
Ipswich River		
Bostic Chemical Group		
Rockport MTP	1.08E-02	3.12E-02
Ipswich Public	2.04E-02	1.40E-01
North Shore		
South Essex SD	4.00E+00	2.48E+01
New England Power		
Gloucester	9.20E-01	1.76E+00
Lynn Water & Sewer	8.80E+00	3.32E+01
Manchester WTP FACA	3.76E-02	1.52E-01
Swampscott WPCP	4.40E-01	1.52E+00
General Electric		
Refuse Energy Systems		
Subtotal	1.42E+01	6.16E+01

POTW Point Sources PCBs	Lower Estimate (kg/yr)	Higher Estimate (kg/yr)
Boston Harbor Drainage Basin		
Boston Harbor		
MWRA - Deer Island	1.75E+02	1.75E+02
MWRA - Nut Island	7.50E+01	7.50E+01
MWRA - Nut Island Sludge Outfall	1.50E+02	1.50E+02
Mystic River		
Boston Edison (Boston)		
Monsanto		
Exxon Oil * Island End Terminal		
Boston Edison (Everett)		
Cambridge Electric		
Charles River		
Norfolk-Walpole	1.88E-02	2.36E-02
Charles River PCD		
Medfield WWTP	3.20E-02	4.00E-02
Neponset River		
Plymouth Rubber Co.		
Foxboro Co. Neponset		
Subtotal	4.00E+02	4.00E+02
South Shore Drainage Basin		
Hull WTP	8.80E-02	5.20E-01
Plymouth	3.44E-01	4.80E-01
Marshfield WTP		
Boston Edison-Pilgrim Pl.		
Rockland WTP	1.44E-01	1.44E-01
Subtotal	5.76E-01	1.14E+00
Cape Cod Drainage Basin		
Canal Electric-Pl.		
Subtotal	0.00E+00	0.00E+00
TOTAL	4.16E+02	4.68E+02

Table 16. Estimated point source loadings of phthalate esters .

POTW Point Sources Phthalate Esters	Lower Estimate (kg/yr)	Higher Estimate (kg/yr)
Merrimack River Drainage Basin		
Concord River		
Westborough WTP	1.43E+00	4.29E+00
Billerica-Letchworth WTP FACA	1.43E+00	4.29E+00
Marlborough STP	1.65E+00	4.95E+00
Hudson WWTF FACA	2.86E+00	7.04E+00
Marlborough Westerly WTF	3.52E+00	6.16E+00
Maynard STP	1.98E+00	3.96E+00
Raytheon Corporation		
Concord	1.43E-01	4.40E+00
Silicon Transistor		
Raytheon Co.-Wayland		
NYES Japenamelac WWTP		
Merrimack River		
Amesbury		
Haverhill WPAF	3.19E+00	3.96E+01
AT&T		
Gould Inc. FACA		
Greater Lawrence SD	3.74E+01	7.81E+01
Newburyport WPCF	1.32E+00	3.41E+00
Salisbury Sewer Comm.	2.53E-02	2.09E-01
Exxon Company		
Lowell MSS		
Very Fine Inc.		
Subtotal	5.49E+01	1.56E+02
North Shore Drainage Basin		
Ipswich River		
Bostic Chemical Group		
Rockport MTP	2.97E-01	8.58E-01
Ipswich Public	5.61E-01	3.85E+00
North Shore		
South Essex SD	1.10E+02	6.82E+02
New England Power		
Gloucester	2.53E+01	4.84E+01
Lynn Water & Sewer	2.42E+02	9.13E+02
Manchester WTP FACA	1.03E+00	4.18E+00
Swampscott WPCP	1.21E+01	4.18E+01
General Electric		
Refuse Energy Systems		
Subtotal	3.91E+02	1.69E+03

POTW Point Sources Phthalate Esters	Lower Estimate (kg/yr)	Higher Estimate (kg/yr)
Boston Harbor Drainage Basin		
Boston Harbor		
MWRA - Deer Island	4.90E+03	4.90E+03
MWRA - Nut Island	2.10E+03	2.10E+03
MWRA - Nut Island Sludge Outfall	1.80E+03	1.80E+03
Mystic River		
Boston Edison (Boston)		
Monsanto		
Exxon Oil * Island End Terminal		
Boston Edison (Everett)		
Cambridge Electric		
Charles River		
Norfolk-Walpole	5.17E-01	6.49E-01
Charles River PCD		
Medfield WWTP	8.80E-01	1.10E+00
Neponset River		
Plymouth Rubber Co.		
Foxboro Co. Neponset		
Subtotal	8.80E+03	8.80E+03
South Shore Drainage Basin		
Hull WTP	2.42E+00	1.43E+01
Plymouth	9.46E+00	1.32E+01
Marshfield WTP		
Boston Edison-Pilgrim Pl.		
Rockland WTP	3.96E+00	3.96E+00
Subtotal	1.58E+01	3.15E+01
Cape Cod Drainage Basin		
Canal Electric-Pl.		
Subtotal	0.00E+00	0.00E+00
TOTAL	9.26E+03	1.07E+04

Table 17. Estimated point source loadings of cadmium based solely on DMR data.

Point Sources Cadmium: DMRs	Lower Estimate (kg/yr)	Higher Estimate (kg/yr)
Merrimack River Drainage Basin		
Concord River		
Westborough WTP		
Billerica-Letchworth WTP FACA		
Marlborough STP		
Hudson WWTF FACA		
Marlborough Westerly WTF		
Maynard STP		
Raytheon Corporation		
Concord		
Silicon Transistor		
Raytheon Co.-Wayland		
NYES Japenamelac WWTP		
Merrimack River		
Amesbury		
Haverhill WPAF		
AT&T	3.20E+00	3.20E+00
Gould Inc. FACA		
Greater Lawrence SD		
Newburyport WPCF (considered high)	4.40E+03	2.30E+04
Salisbury Sewer Comm.		
Exxon Company		
Lowell MSS	7.40E+01	7.40E+01
Very Fine Inc.		
Subtotal	4.48E+03	2.31E+04
North Shore Drainage Basin		
Ipswich River		
Bostic Chemical Group		
Rockport MTP		
Ipswich Public		
North Shore		
South Essex SD		
New England Power		
Gloucester		
Lynn Water & Sewer		
Manchester WTP FACA		
Swampscott WPCP		
General Electric		
Refuse Energy Systems		
Subtotal	0.00E+00	0.00E+00

Point Sources Cadmium: DMRs	Lower Estimate (kg/yr)	Higher Estimate (kg/yr)
Boston Harbor Drainage Basin		
Boston Harbor		
MWRA - Deer Island	1.20E+03	1.20E+03
MWRA - Nut Island	5.00E+02	5.00E+02
MWRA - Nut Island Sludge Outfall	3.70E+02	3.70E+02
Mystic River		
Boston Edison (Boston)		
Monsanto		
Exxon Oil * Island End Terminal		
Boston Edison (Everett)		
Cambridge Electric		
Charles River		
Norfolk-Walpole		
Charles River PCD		
Medfield WWTP		
Neponset River		
Plymouth Rubber Co.		
Foxboro Co. Neponset	2.40E+01	5.50E+01
Subtotal	2.09E+03	2.13E+03
South Shore Drainage Basin		
Hull WTP		
Plymouth		
Marshfield WTP		
Boston Edison-Pilgrim Pl.		
Rockland WTP		
Subtotal	0.00E+00	0.00E+00
Cape Cod Drainage Basin		
Canal Electric-Pl.	0.00E+00	0.00E+00
Subtotal	0.00E+00	0.00E+00
TOTAL	6.57E+03	2.52E+04

Table 18. Estimated point source loadings of cadmium based on DMR data as well as the Cd:TSS Ratio.

Point Sources Cadmium: DMRs and Cd:TSS Ratios for POTWs	Lower Estimate (kg/yr)	Higher Estimate (kg/yr)
Merrimack River Drainage Basin		
Concord River		
Westborough WTP	3.63E-01	1.09E+00
Billerica-Letchworth WTP FACA	3.63E-01	1.09E+00
Marlborough STP	4.19E-01	1.26E+00
Hudson WWTF FACA	7.26E-01	1.79E+00
Marlborough Westerly WTF	8.93E-01	1.56E+00
Maynard STP	5.02E-01	1.00E+00
Raytheon Corporation		
Concord		
Silicon Transistor		
Raytheon Co.-Wayland		
NYES Japenamelac WWTP		
Merrimack River		
Amesbury		
Haverhill WPAF	8.09E-01	1.00E+01
AT&T	3.20E+00	3.20E+00
Gould Inc. FACA		
Greater Lawrence SD	9.49E+00	1.98E+01
Newburyport WPCF	3.35E-01	8.65E-01
Salisbury Sewer Comm.	6.42E-03	5.30E-02
Exxon Company		
Lowell MSS	7.40E+01	7.40E+01
Very Fine Inc.		
Subtotal	9.11E+01	1.16E+02
North Shore Drainage Basin		
Ipswich River		
Bostic Chemical Group		
Rockport MTP	7.53E-02	2.18E-01
Ipswich Public	1.42E-01	9.77E-01
North Shore		
South Essex SD	2.79E+01	1.73E+02
New England Power		
Gloucester	6.42E+00	1.23E+01
Lynn Water & Sewer	6.14E+01	2.32E+02
Manchester WTP FACA	2.62E-01	1.06E+00
Swampscott WPCP	3.07E+00	1.06E+01
General Electric		
Refuse Energy Systems		
Subtotal	9.93E+01	4.30E+02

Point Sources Cadmium: DMRs and Cd:TSS Ratios for POTWs	Lower Estimate (kg/yr)	Higher Estimate (kg/yr)
Boston Harbor Drainage Basin		
Boston Harbor		
MWRA - Deer Island	1.20E+03	1.20E+03
MWRA - Nut Island	5.00E+02	5.00E+02
MWRA - Nut Island Sludge Outfall	3.70E+02	3.70E+02
Mystic River		
Boston Edison (Boston)		
Monsanto		
Exxon Oil * Island End Terminal		
Boston Edison (Everett)		
Cambridge Electric		
Charles River		
Norfolk-Walpole		
Charles River PCD		
Medfield WWTP	2.23E-01	2.79E-01
Neponset River		
Plymouth Rubber Co.		
Foxboro Co. Neponset		
Subtotal	2.07E+03	2.07E+03
South Shore Drainage Basin		
Hull WTP	6.14E-01	3.63E+00
Plymouth	2.40E+00	3.35E+00
Marshfield WTP		
Boston Edison-Pilgrim Pl.		
Rockland WTP	1.00E+00	1.00E+00
Subtotal	4.02E+00	7.98E+00
Cape Cod Drainage Basin		
Canal Electric-Pl.		
Subtotal	0.00E+00	0.00E+00
TOTAL	2.26E+03	2.62E+03

Table 19. Estimated point source loadings of chromium based solely on DMR data.

Point Sources Chromium: DMRs	Lower Estimate (kg/yr)	Higher Estimate (kg/yr)
Merrimack River Drainage Basin		
Concord River		
Westborough WTP		
Billerica-Letchworth WTP FACA	2.30E+02	2.30E+02
Marlborough STP		
Hudson WWTF FACA		
Marlborough Westerly WTF	1.20E+02	1.20E+02
Maynard STP		
Raytheon Corporation		
Concord		
Silicon Transistor		
Raytheon Co.-Wayland	1.20E+00	1.70E+00
NYES Japenamelac WWTP	3.90E+00	1.10E+01
Merrimack River		
Amesbury	4.20E+01	1.10E+02
Haverhill WPAF		
AT&T	8.40E+01	4.30E+02
Gould Inc. FACA		
Greater Lawrence SD	1.30E+02	1.30E+02
Newburyport WPCF	2.70E+01	6.70E+01
Salisbury Sewer Comm.		
Exxon Company		
Lowell MSS	1.80E+02	1.80E+02
Very Fine Inc.		
Subtotal	8.18E+02	1.28E+03
North Shore Drainage Basin		
Ipswich River		
Bostic Chemical Group		
Rockport MTP		
Ipswich Public		
North Shore		
South Essex SD		
New England Power	3.30E+03	3.30E+03
Gloucester		
Lynn Water & Sewer		
Manchester WTP FACA	5.50E+01	5.50E+01
Swampscott WPCP		
General Electric		
Refuse Energy Systems		
Subtotal	3.36E+03	3.36E+03

Point Sources Chromium: DMRs	Lower Estimate (kg/yr)	Higher Estimate (kg/yr)
Boston Harbor Drainage Basin		
Boston Harbor		
MWRA - Deer Island	8.40E+03	8.40E+03
MWRA - Nut Island	3.60E+03	3.60E+03
MWRA - Nut Island Sludge Outfall	3.70E+03	3.70E+03
Mystic River		
Boston Edison (Boston)		
Monsanto		
Exxon Oil * Island End Terminal		
Boston Edison (Everett)	2.90E+01	2.90E+01
Cambridge Electric		
Charles River		
Norfolk-Walpole		
Charles River PCD		
Medfield WWTP		
Neponset River		
Plymouth Rubber Co.		
Foxboro Co. Neponset	3.10E-05	3.10E-05
Subtotal	1.57E+04	1.57E+04
South Shore Drainage Basin		
Hull WTP		
Plymouth		
Marshfield WTP		
Boston Edison-Pilgrim Pl.		
Rockland WTP		
Subtotal	0.00E+00	0.00E+00
Cape Cod Drainage Basin		
Canal Electric-Pl.		
Subtotal		0.00E+00
TOTAL	1.99E+04	2.04E+04

Table 20. Estimated point source loadings of chromium based on DMR data as well as the Cr:TSS ratio.

Point Sources Chromium: DMRs and Cr:TSS Ratios for POTWs	Lower Estimate (kg/yr)	Higher Estimate (kg/yr)
Merrimack River Drainage Basin		
Concord River		
Westborough WTP	1.95E+01	5.85E+01
Billerica-Letchworth WTP FACA	2.30E+02	2.30E+02
Marlborough STP	2.25E+01	6.75E+01
Hudson WWTF FACA	3.90E+01	9.60E+01
Marlborough Westerly WTF	1.20E+02	1.20E+02
Maynard STP	2.70E+01	5.40E+01
Raytheon Corporation		
Concord		
Silicon Transistor		
Raytheon Co.-Wayland	1.20E+00	1.70E+00
NYES Japenamelac WWTP	3.90E+00	1.10E+01
Merrimack River		
Amesbury	4.20E+01	1.10E+02
Haverhill WPAF	4.35E+01	5.40E+02
AT&T	8.40E+01	4.30E+02
Gould Inc. FACA		
Greater Lawrence SD	1.30E+02	1.30E+02
Newburyport WPCF	2.70E+01	6.70E+01
Salisbury Sewer Comm.	3.45E-01	2.85E+00
Exxon Company		
Lowell MSS	1.80E+02	1.80E+02
Very Fine Inc.		
Subtotal	9.70E+02	2.10E+03
North Shore Drainage Basin		
Ipswich River		
Bostic Chemical Group		
Rockport MTP	4.05E+00	1.17E+01
Ipswich Public	7.65E+00	5.25E+01
North Shore		
South Essex SD	1.50E+03	9.30E+03
New England Power	3.30E+03	3.30E+03
Gloucester	3.45E+02	6.60E+02
Lynn Water & Sewer	3.30E+03	1.25E+04
Manchester WTP FACA	5.50E+01	5.50E+01
Swampscott WPCP	1.65E+02	5.70E+02
General Electric		
Refuse Energy Systems		
Subtotal	8.68E+03	2.64E+04

Point Sources Chromium: DMRs and Cr:TSS Ratios for POTWs	Lower Estimate (kg/yr)	Higher Estimate (kg/yr)
Boston Harbor Drainage Basin		
Boston Harbor		
MWRA - Deer Island	8.40E+03	8.40E+03
MWRA - Nut Island	3.60E+03	3.60E+03
MWRA - Nut Island Sludge Outfall	3.70E+03	3.70E+03
Mystic River		
Boston Edison (Boston)		
Monsanto		
Exxon Oil * Island End Terminal		
Boston Edison (Everett)	2.90E+01	2.90E+01
Cambridge Electric		
Charles River		
Norfolk-Walpole		
Charles River PCD		
Medfield WWTP	1.20E+01	1.50E+01
Neponset River		
Plymouth Rubber Co.		
Foxboro Co. Neponset	3.10E-05	3.10E-05
Subtotal	1.57E+04	1.57E+04
South Shore Drainage Basin		
Hull WTP	3.30E+01	1.95E+02
Plymouth	1.29E+02	1.80E+02
Marshfield WTP		
Boston Edison-Pilgrim Pl.		
Rockland WTP	5.40E+01	5.40E+01
Subtotal	2.16E+02	4.29E+02
Cape Cod Drainage Basin		
Canal Electric-Pl.	0.00E+00	0.00E+00
Subtotal		0.00E+00
TOTAL		

Table 21. Estimated point source loadings of copper.

Point Sources Copper: DMRs	Lower Estimate (kg/yr)	Higher Estimate (kg/yr)
Merrimack River Drainage Basin		
Concord River		
Westborough WTP	3.00E+02	3.00E+02
Billerica-Letchworth WTP FACA		
Marlborough STP	1.10E+02	1.10E+02
Hudson WWTF FACA	2.70E+02	2.70E+02
Marlborough Westerly WTF	8.30E+01	8.30E+01
Maynard STP	4.10E+00	1.70E+02
Raytheon Corporation		
Concord	7.80E+00	1.40E+02
Silicon Transistor	1.90E+00	6.10E+00
Raytheon Co.-Wayland	1.70E+00	2.40E+01
NYES Japenamelac WWTP	4.10E-01	4.10E-01
Merrimack River		
Amesbury	6.30E+01	1.70E+03
Haverhill WPAF	2.20E+03	2.20E+03
AT&T	2.20E+03	7.90E+03
Gould Inc. FACA		
Greater Lawrence SD	9.90E+02	3.30E+03
Newburyport WPCF (considered high)	2.70E+01	2.30E+02
Salisbury Sewer Comm.		
Exxon Company		
Lowell MSS	1.20E+03	1.30E+03
Very Fine Inc.	9.40E+00	1.10E+01
Subtotal	7.47E+03	1.77E+04
North Shore Drainage Basin		
Ipswich River		
Bostic Chemical Group		
Rockport MTP		
Ipswich Public		
North Shore		
South Essex SD	2.50E+03	2.50E+03
New England Power	4.40E-01	4.20E+01
Gloucester	1.00E+02	1.00E+02
Lynn Water & Sewer		
Manchester WTP FACA	4.40E+01	4.40E+01
Swampscott WPCP		
General Electric		
Refuse Energy Systems		
Subtotal	2.64E+03	2.69E+03

Point Sources Copper: DMRs	Lower Estimate (kg/yr)	Higher Estimate (kg/yr)
Boston Harbor Drainage Basin		
Boston Harbor		
MWRA - Deer Island	3.10E+04	3.10E+04
MWRA - Nut Island	1.30E+04	1.30E+04
MWRA - Nut Island Sludge Outfall	2.20E+04	2.20E+04
Mystic River		
Boston Edison (Boston)	6.00E+00	6.20E+00
Monsanto		
Exxon Oil * Island End Terminal		
Boston Edison (Everett)	2.80E+01	5.70E+01
Cambridge Electric		
Charles River		
Norfolk-Walpole		
Charles River PCD		
Medfield WWTP		
Neponset River		
Plymouth Rubber Co.		
Foxboro Co. Neponset		
Subtotal	6.60E+04	6.61E+04
South Shore Drainage Basin		
Hull WTP	1.50E+02	1.50E+02
Plymouth		
Marshfield WTP		
Boston Edison-Pilgrim Pl.		
Rockland WTP		
Subtotal	1.50E+02	1.50E+02
Cape Cod Drainage Basin		
Canal Electric-Pl.	2.60E+01	3.00E+01
Subtotal	2.60E+01	3.00E+01
TOTAL	7.63E+04	8.67E+04

Table 22. Estimated point source loadings of lead based solely on the DMR data.

Point Sources Lead: DMRs	Lower Estimate (kg/yr)	Higher Estimate (kg/yr)
Merrimack River Drainage Basin		
Concord River		
Westborough WTP		
Billerica-Letchworth WTP FACA	4.60E+03	4.60E+03
Marlborough STP		
Hudson WWTF FACA		
Marlborough Westerly WTF		
Maynard STP	4.80E+00	7.60E+00
Raytheon Corporation		
Concord		
Silicon Transistor	4.40E+00	5.70E+00
Raytheon Co.-Wayland	4.80E+00	6.10E+00
NYES Japenamelac WWTP		
Merrimack River		
Amesbury	2.10E+01	5.70E+01
Haverhill WPAF		
AT&T	8.60E+01	7.70E+02
Gould Inc. FACA		
Greater Lawrence SD	1.00E+02	1.00E+02
Newburyport WPCF (considered high)	5.30E+01	1.20E+02
Salisbury Sewer Comm.		
Exxon Company		
Lowell MSS	3.80E+02	3.80E+02
Very Fine Inc.	1.40E+00	2.20E+00
Subtotal	5.26E+03	6.05E+03
North Shore Drainage Basin		
Ipswich River		
Bostic Chemical Group		
Rockport MTP		
Ipswich Public		
North Shore		
South Essex SD	1.90E+03	1.90E+03
New England Power		
Gloucester		
Lynn Water & Sewer		
Manchester WTP FACA	2.90E+02	2.90E+02
Swampscott WPCP		
General Electric		
Refuse Energy Systems		
Subtotal	2.19E+03	2.19E+03

Point Sources **Lead: DMRs**	**Lower Estimate (kg/yr)**	**Higher Estimate (kg/yr)**
Boston Harbor Drainage Basin		
Boston Harbor		
MWRA - Deer Island	7.70E+03	7.70E+03
MWRA - Nut Island	3.30E+03	3.30E+03
MWRA - Nut Island Sludge Outfall	3.30E+03	3.30E+03
Mystic River		
Boston Edison (Boston)		
Monsanto		
Exxon Oil * Island End Terminal		
Boston Edison (Everett)	4.80E+01	4.80E+01
Cambridge Electric		
Charles River		
Norfolk-Walpole		
Charles River PCD		
Medfield WWTP		
Neponset River		
Plymouth Rubber Co.		
Foxboro Co. Neponset	1.10E+01	1.10E+01
Subtotal	1.44E+04	1.44E+04
South Shore Drainage Basin		
Hull WTP		
Plymouth		
Marshfield WTP		
Boston Edison-Pilgrim Pl.		
Rockland WTP		
Subtotal		
Cape Cod Drainage Basin		
Canal Electric-Pl.		
Subtotal		
TOTAL	2.18E+04	2.26E+04

Table 23. Estimated point source loadings of lead based on the DMR data as well as the Pb:TSS ratio.

Point Sources Lead : DMRs and Pb:TSS Ratios for POTWs	Lower Estimate (kg/yr)	Higher Estimate (kg/yr)
Merrimack River Drainage Basin		
Concord River		
Westborough WTP	2.34E+01	7.02E+01
Billerica-Letchworth WTP FACA	4.60E+03	4.60E+03
Marlborough STP	2.70E+01	8.10E+01
Hudson WWTF FACA	4.68E+01	1.15E+02
Marlborough Westerly WTF	5.76E+01	1.01E+02
Maynard STP	4.80E+00	7.60E+00
Raytheon Corporation		
Concord		
Silicon Transistor	4.40E+00	5.70E+00
Raytheon Co.-Wayland	4.80E+00	6.10E+00
NYES Japenamelac WWTP		
Merrimack River		
Amesbury	2.10E+01	5.70E+01
Haverhill WPAF	5.22E+01	6.48E+02
AT&T	8.60E+01	7.70E+02
Gould Inc. FACA		
Greater Lawrence SD	1.00E+02	1.00E+02
Newburyport WPCF	5.30E+01	1.20E+02
Salisbury Sewer Comm.	4.14E-01	3.42E+00
Exxon Company		
Lowell MSS	3.80E+02	3.80E+02
Very Fine Inc.	1.40E+00	2.20E+00
Subtotal	5.46E+03	7.07E+03
North Shore Drainage Basin		
Ipswich River		
Bostic Chemical Group		
Rockport MTP	4.86E+00	1.40E+01
Ipswich Public	9.18E+00	6.30E+01
North Shore		
South Essex SD	1.90E+03	1.90E+03
New England Power		
Gloucester	4.14E+02	7.92E+02
Lynn Water & Sewer	3.96E+03	1.49E+04
Manchester WTP FACA	2.90E+02	2.90E+02
Swampscott WPCP	1.98E+02	6.84E+02
General Electric		
Refuse Energy Systems		
Subtotal	6.76E+03	1.86E+04

Point Sources **Lead : DMRs and Pb:TSS Ratios for POTWs**	**Lower Estimate (kg/yr)**	**Higher Estimate (kg/yr)**
Boston Harbor Drainage Basin		
Boston Harbor		
MWRA - Deer Island	7.70E+03	7.70E+03
MWRA - Nut Island	3.30E+03	3.30E+03
MWRA - Nut Island Sludge Outfall	3.30E+03	3.30E+03
Mystic River		
Boston Edison (Boston)		
Monsanto		
Exxon Oil * Island End Terminal		
Boston Edison (Everett)	4.80E+01	4.80E+01
Cambridge Electric		
Charles River		
Norfolk-Walpole		
Charles River PCD		
Medfield WWTP	1.44E+01	1.80E+01
Neponset River		
Plymouth Rubber Co.		
Foxboro Co. Neponset	1.10E+01	1.10E+01
Subtotal	1.44E+04	1.44E+04
South Shore Drainage Basin		
Hull WTP	3.96E+01	2.34E+02
Plymouth	1.55E+02	2.16E+02
Marshfield WTP		
Boston Edison-Pilgrim Pl.		
Rockland WTP	6.48E+01	6.48E+01
Subtotal		
Cape Cod Drainage Basin		
Canal Electric-Pl.		
Subtotal		
TOTAL		

Table 24. Estimated point source loadings of nickel.

Point Sources Nickel: DMRs	Lower Estimate (kg/yr)	Higher Estimate (kg/yr)
Merrimack River Drainage Basin		
Concord River		
Westborough WTP		
Billerica-Letchworth WTP FACA		
Marlborough STP		
Hudson WWTF FACA		
Marlborough Westerly WTF	1.41E+03	1.41E+03
Maynard STP		
Raytheon Corporation		
Concord		
Silicon Transistor		
Raytheon Co.-Wayland		
NYES Japenamelac WWTP		
Merrimack River		
Amesbury	6.31E+01	1.38E+02
Haverhill WPAF		
AT&T	2.36E+02	7.49E+03
Gould Inc. FACA		
Greater Lawrence SD	3.13E+02	3.13E+02
Newburyport WPCF (considered high)	4.43E+01	2.43E+02
Salisbury Sewer Comm.		
Exxon Company		
Lowell MSS	3.32E+02	1.25E+03
Very Fine Inc.		
Subtotal	2.40E+03	1.08E+04
North Shore Drainage Basin		
Ipswich River		
Bostic Chemical Group		
Rockport MTP		
Ipswich Public		
North Shore		
South Essex SD	1.17E+03	1.17E+03
New England Power	1.90E+00	1.05E+02
Gloucester		
Lynn Water & Sewer		
Manchester WTP FACA	3.55E+02	3.55E+02
Swampscott WPCP		
General Electric		
Refuse Energy Systems		
Subtotal	1.53E+03	1.63E+03

Point Sources Nickel: DMRs	**Lower Estimate (kg/yr)**	**Higher Estimate (kg/yr)**
Boston Harbor Drainage Basin		
Boston Harbor		
MWRA - Deer Island	5.11E+03	5.11E+03
MWRA - Nut Island	2.19E+03	2.19E+03
MWRA - Nut Island Sludge Outfall	2.20E+03	2.20E+03
Mystic River		
Boston Edison (Boston)	1.66E+00	4.03E+01
Monsanto		
Exxon Oil * Island End Terminal		
Boston Edison (Everett)	6.76E+02	7.00E+02
Cambridge Electric		
Charles River		
Norfolk-Walpole		
Charles River PCD		
Medfield WWTP		
Neponset River		
Plymouth Rubber Co.		
Foxboro Co. Neponset	3.07E+01	3.07E+01
Subtotal	1.02E+04	1.03E+04
South Shore Drainage Basin		
Hull WTP		
Plymouth		
Marshfield WTP		
Boston Edison-Pilgrim Pl.		
Rockland WTP		
Subtotal	0.00E+00	0.00E+00
Cape Cod Drainage Basin		
Canal Electric-Pl.		
Subtotal		
TOTAL	1.41E+04	2.28E+04

Table 25. Estimated point source loadings of zinc.

Point Sources Zinc: DMRs	Lower Estimate (kg/yr)	Higher Estimate (kg/yr)
Merrimack River Drainage Basin		
Concord River		
Westborough WTP	3.60E+02	3.60E+02
Billerica-Letchworth WTP FACA	7.20E+02	7.20E+02
Marlborough STP		
Hudson WWTF FACA		
Marlborough Westerly WTF		
Maynard STP	1.40E+02	2.30E+02
Raytheon Corporation	5.50E+00	5.50E+00
Concord	2.90E+01	8.60E+01
Silicon Transistor	2.40E+00	2.40E+00
Raytheon Co.-Wayland	1.10E+01	1.10E+01
NYES Japenamelac WWTP	3.70E-01	3.70E-01
Merrimack River		
Amesbury	2.50E+02	2.50E+02
Haverhill WPAF	1.10E+03	1.10E+03
AT&T	3.00E+02	3.00E+02
Gould Inc. FACA		
Greater Lawrence SD	1.90E+03	3.10E+03
Newburyport WPCF (considered high)	1.30E+02	2.10E+02
Salisbury Sewer Comm.		
Exxon Company		
Lowell MSS	2.50E+03	3.90E+03
Very Fine Inc.	1.50E+01	3.10E+01
Subtotal	7.46E+03	1.03E+04
North Shore Drainage Basin		
Ipswich River		
Bostic Chemical Group		
Rockport MTP		
Ipswich Public		
North Shore		
South Essex SD	5.30E+03	5.30E+03
New England Power	5.70E-01	3.20E+01
Gloucester	2.40E+02	2.40E+02
Lynn Water & Sewer		
Manchester WTP FACA	8.30E+02	8.30E+02
Swampscott WPCP		
General Electric		
Refuse Energy Systems		
Subtotal	6.37E+03	6.40E+03

Point Sources Zinc: DMRs	Lower Estimate (kg/yr)	Higher Estimate (kg/yr)
Boston Harbor Drainage Basin		
Boston Harbor		
MWRA - Deer Island	5.11E+04	5.11E+04
MWRA - Nut Island	2.19E+04	2.19E+04
MWRA - Nut Island Sludge Outfall	4.70E+04	4.70E+04
Mystic River		
Boston Edison (Boston)	1.80E+01	9.40E+01
Monsanto	1.90E+01	1.90E+01
Exxon Oil * Island End Terminal		
Boston Edison (Everett)	1.90E+01	8.00E+01
Cambridge Electric		
Charles River		
Norfolk-Walpole		
Charles River PCD		
Medfield WWTP		
Neponset River		
Plymouth Rubber Co.		
Foxboro Co. Neponset		
Subtotal	1.20E+05	1.20E+05
South Shore Drainage Basin		
Hull WTP	1.10E+04	1.10E+04
Plymouth		
Marshfield WTP		
Boston Edison-Pilgrim Pl.		
Rockland WTP		
Subtotal	1.10E+04	1.10E+04
Cape Cod Drainage Basin		
Canal Electric-Pl.		
Subtotal	0.00E+00	0.00E+00
TOTAL	1.45E+05	1.48E+05

Table 26. Estimated point source loadings of mercury.

Point Sources Mercury	Low(kg/yr	High (kg/yr)
Merrimack River Drainage Basin		
Concord River		
Westborough WTP	2.30E-02	6.90E-02
Billerica-Letchworth WTP FACA	2.30E-02	6.90E-02
Marlborough STP	2.66E-02	7.97E-02
Hudson WWTF FACA	4.60E-02	1.13E-01
Marlborough Westerly WTF	5.66E-02	9.91E-02
Maynard STP	3.19E-02	6.37E-02
Raytheon Corporation		
Concord		
Silicon Transistor		
Raytheon Co.-Wayland		
NYES Japenamelac WWTP	2.30E-01	1.19E+00
Merrimack River		
Amesbury		
Haverhill WPAF	5.13E-02	6.37E-01
AT&T		
Gould Inc. FACA		
Greater Lawrence SD	6.02E-01	1.26E+00
Newburyport WPCF	2.12E-02	5.49E-02
Salisbury Sewer Comm.	4.07E-04	3.36E-03
Exxon Company		
Lowell MSS	6.37E-03	6.37E-03
Very Fine Inc.		
Subtotal	1.12E+00	3.64E+00
North Shore Drainage Basin		
Ipswich River		
Bostic Chemical Group		
Rockport MTP	4.78E-03	1.38E-02
Ipswich Public	9.03E-03	6.20E-02
North Shore	0.00E+00	0.00E+00
South Essex SD	1.77E+00	1.10E+01
New England Power		
Gloucester	4.07E-01	7.79E-01
Lynn Water & Sewer	3.89E+00	1.47E+01
Manchester WTP FACA	1.66E-02	6.73E-02
Swampscott WPCP	1.95E-01	6.73E-01
General Electric		
Refuse Energy Systems		
Subtotal	6.30E+00	2.73E+01

Point Sources Mercury	Low(kg/yr	High (kg/yr)
Boston Harbor Drainage Basin		
Boston Harbor		
MWRA - Deer Island	1.10E+02	110
MWRA - Nut Island		
MWRA - Nut Island Sludge Outfall	1.10E+02	110
Mystic River		
Boston Edison (Boston)		
Monsanto		
Exxon Oil * Island End Terminal		
Boston Edison (Everett)		
Cambridge Electric		
Charles River		
Norfolk-Walpole	8.32E-03	1.04E-02
Charles River PCD	3.54E+00	5.49E+00
Medfield WWTP	1.42E-02	1.77E-02
Neponset River		
Plymouth Rubber Co.		
Foxboro Co. Neponset		
Subtotal	2.24E+02	2.26E+02
South Shore Drainage Basin		
Hull WTP	3.89E-02	2.30E-01
Plymouth	1.52E-01	2.12E-01
Marshfield WTP		
Boston Edison-Pilgrim Pl.		
Rockland WTP	6.37E-02	6.37E-02
Subtotal	2.55E-01	5.06E-01
Cape Cod Drainage Basin		
Canal Electric-Pl.		
Subtotal		
TOTAL	2.31E+02	2.57E+02

A PCS retrieval was performed to identify the Massachusetts minor dischargers. The minor dischargers were aggregated by two major drainage basins: Merrimack River basin and Massachusetts Coastal basin. The Merrimack basin included 88 minor point sources south of the Pawtucket dam in Lowell, MA. There were 225 minor dischargers within the Massachusetts Coastal River basin. The minor dischargers were further subdivided according to the minor river subbasins within one of the two major river basins. A key identified all minor dischargers by facility name and NPDES ID number.

A general facility report and 1989 effluent statistical summary also was requested from the PCS retrieval system for each identified minor discharger. If no general facility information and/or effluent summary statistics were available, then we reviewed selected hard copy permit files of Massachusetts minor dischargers. These files are maintained at the EPA Region I offices in Boston. We reviewed approximately 30 permit files for minor dischargers to establish the general nature of these discharges; this is approximately 10% of the minor point sources discharging to the drainage areas for which there are permits.

The permitted minor discharges reviewed by us were found to consist of stormwater runoff from drainage systems, sanitary waste water, boiler blowdown, noncontact cooling water from air compressor units, refrigeration units and heat exchange pumps. The permitted storm drainage systems typically contained oil/water separators. Occasionally, permits for groundwater recovery wells were found. The groundwater discharge permits required that the treated effluent must meet drinking water standards before being released into a receiving water body. According to EPA personnel, there are approximately "a couple hundred" of these permitted groundwater remediation systems within the state of Massachusetts.

Because of the nature of the minor discharges (i.e. stormwater runoff), the discharges may only occur periodically, unlike the discharges from the major NPDES facilities which are often continuous. Parameters that are typically monitored within the effluents from minor NPDES facilities are temperature, oil & grease, conductivity, total suspended and settleable solids. Cobalt, phthalate esters, chromium and residual chlorine were among the parameters measured occasionally. For a given effluent limit, daily maximum or average monthly are usually reported based on the analysis of grab samples. From our investigation of minor permits, the flow from the outfalls of the minor NPDES facilities ranged from 400 to 42,000,000 GPD per outfall.

The wide range of effluent flows and limited effluent data for the minor NPDES dischargers prevented the estimation of pollutant loads for this particular group of point sources. Most of the permits are for stormwater outfalls and, to some, extent, we have taken these into account under nonpoint sources in Section 5. Another major category of minor dischargers included noncontact cooling water discharges. It is likely that these dischargers will not contain high concentrations of contaminants. Small sanitary wastewater discharges are also included among the minor point sources and will contribute to the loadings of nutrients and other pollutants. These loadings may be important at the local level.

4.3.4 Anticipated Changes in Loadings Due to Upgrade of MWRA Effluents

Current MWRA effluents include the discharge of sludges from Nut and Deer Island, primary treated wastewater from these two facilities, and CSO discharges. Upgrade of the system will involve removal of the sludge discharges and abatement of CSOs via enhancing the capability of the system to handle stormwater. In addition, increased treatment of the wastewater will reduce loadings of conventional as well as toxic pollutants. Here, we provide estimates of the reduction in loadings associated with the additional treatment of wastewater (Table 27). Loads associated with complete secondary treatment are shown. Depending on the pollutant, load reductions range from a few percent to over 95%. Thus, elimination of sludge and complete secondary treatment should have a relatively large impact on overall point source loads to Massachusetts Bay. It is anticipated that the treatment of MWRA effluents may involve several phases which include some combination of enhanced primary and secondary treatment. At this writing, the schedules for these activities is still not clear. Thus, we project that future loadings from MWRA effluents will be within the range shown in Table 27.

4.3.5 Data Quality for Point Source Estimates

There are several sources of uncertainty in estimating loadings for point sources. One of the major sources of uncertainty is that discharge monitoring is performed on only a subset of nutrients, organic compounds, or metals at any one facility and, therefore, there are a number of data gaps.

Discharge monitoring may occur in a manner that is aperiodic or uneven. In the case of major stormwater outfalls, monitoring is event oriented. In the case of minor dischargers, the overall availability of data may be limited.

Loadings developed on a drainage area basin may not reflect the loadings received by Massachusetts Bays. A number of chemical and physical processes (e.g., volatilization, biodegradation, sedimentation) will affect the fate and transport of materials discharged from point sources within the drainage areas. To provide a lower bound for direct point source loadings, we have made a separate estimate for major "coastal" dischargers located within the Massachusetts coastal zone. These estimates exclude all the dischargers on the Merrimack Drainage Area, include all those for the North Shore and South Shore and the Boston Harbor effluents.

Data quality for one set of compounds, PAHs, is especially uncertain, because few data are available. Because the concentrations that we estimated in effluents may be too high, we checked our total loads for the MWRA outfalls using the ratio of PAH:TSS in the MWRA sludge. If 23,000 mt solids/yr are discharged in the sludge, and 62,000 mt are discharged in the effluent, then the effluent discharges approximately 2.7 times more solids than the sludge. Using this ratio and our data for inputs from sludge, PAH discharges from MWRA effluent would range from 124-5,830 kg/yr. This range is approximately the same as the 624-6,230 kg/yr that we calculated.

We also checked PAH data using a more recent estimate from the MWRA (personal communication, M. Connor, MWRA) that sludge inputs account for approximately 365 kg/yr. Using the same PAH:TSS ratio, MWRA effluents would contribute 986 kg PAHs/yr, a value just slightly higher than our lower estimates.

Table 27. Projected future loadings for MWRA effluents (kg/yr).

MWRA Wastewater present and future Constituent	Primary Effluent Load (kg/yr)	Secondary Effluent Load (kg/yr)	Percent Reduction (%)
Conventional Pollutants			
total suspended solids	6.20E+07	2.91E+07	53%
biochemical oxygen demand	7.70E+07	1.99E+07	74%
total nitrogen	1.10E+07	7.06E+06	36%
total phosphorus	2.50E+06	1.19E+06	53%
Volatile Organic Compounds			
acetone	6.96E+04	3.48E+03	95%
benzene	2.74E+03	1.36E+02	95%
bromomethane	1.03E+04	5.17E+02	95%
2-butanone	1.70E+04	1.70E+03	90%
carbon disulfide	5.68E+03	2.84E+02	95%
chlorobenzene	5.60E+03	5.61E+02	90%
chloroform	3.69E+03	3.69E+02	90%
trans-1,2-dichloroethylene	3.17E+03	4.95E+02	84%
ethylbenzene	5.54E+03	2.78E+02	95%
methylene chloride	1.99E+04	9.97E+02	95%
4-methyl-2-pentanone	1.33E+04	1.33E+03	90%
styrene	6.22E+03	6.21E+02	90%
1,1,2,2-tetrachloroethane	5.68E+03	5.68E+02	90%
tetrachloroethylene	1.02E+04	1.02E+03	90%
toluene	1.18E+04	1.18E+03	90%
1,1,1-trichloroethane	4.94E+03	4.10E+02	92%
trichloroethylene	5.78E+03	3.63E+02	94%
xylenes	1.77E+04	8.86E+02	95%
Volatile Acid Extractable and Base Neutral Compounds			
benzoic acid	5.56E+04	5.56E+03	90%
benzyl alcohol	1.43E+04	1.43E+03	90%
bis(2-ethylhexyl)phthalate	1.30E+04	1.30E+03	90%
butylbenzyl phthalate	1.06E+04	5.27E+02	95%
di-n-butyl phthalate	1.13E+04	1.13E+03	90%
1,2-dichlorobenzene	1.24E+04	1.24E+03	90%
diethyl phthalate	1.12E+04	1.12E+03	90%
dimethyl phthalate	1.01E+04	6.65E+02	93%
di-n-octyl phthalate	1.09E+04	1.09E+03	90%
fluorene	2.72E+03	2.71E+02	90%
2-methylnaphthalene	1.02E+04	1.02E+03	90%
2-methylphenol	1.46E+04	1.46E+03	90%
4-methylphenol	1.26E+04	1.26E+03	90%
naphthalene	8.70E+03	4.35E+02	95%
n-nitrosodiphenylamine	1.43E+04	4.43E+03	69%
phenol	8.51E+03	5.33E+02	94%
2,4,5-trichlorophenol	6.65E+04	6.64E+03	90%

MWRA Wastewater present and future Constituent	Primary Effluent Load (kg/yr)	Secondary Effluent Load (kg/yr)	Percent Reduction (%)
Metals			
antimony	1.88E+03	1.08E+03	43%
arsenic	9.46E+02	6.31E+02	33%
cadmium	1.19E+03	6.97E+02	41%
chromium	8.80E+03	3.52E+03	60%
copper	4.31E+04	1.19E+04	72%
lead	6.22E+03	4.95E+03	20%
mercury	6.40E+02	2.05E+02	68%
molybdenum	3.18E+03	1.77E+03	44%
nickel	1.11E+04	8.91E+03	20%
selenium	7.94E+03	4.42E+03	44%
silver	2.08E+03	2.96E+02	86%
zinc	8.61E+04	3.44E+04	60%
Pesticide and Other Compounds			
aldrin	1.10E+02	1.10E+01	90%
4,4-DDT	2.68E+01	2.68E+00	90%
dieldrin	1.17E+01	1.17E+00	90%
heptachlor	1.26E+02	1.39E+01	89%
boron	2.55E+05	2.47E+05	3%
cyanide	1.67E+04	7.42E+03	56%
PCBs	5.27E+02	4.10E+01	92%

1. Current loadings of conventional pollutants are from Menzie-Cura 1991; current and future loadings of toxics are calculated from Table 3.3.1(1-4) of Volume V, Appendix A of Secondary Treatment Facilities Plan; future loadings of conventional pollutants are calculated for average high groundwater days from the Trailer Pilot Plant report prepared by Metcalf and Eddy (1990).

5.0 NONPOINT SOURCE INVENTORY

5.1 General

Several categories of nonpoint sources were evaluated. These included runoff from urban and nonurban areas for the entire drainage areas as well as for a 0.5 mile area along he coastal shoreline, direct discharge of coastal rivers, ocean disposal of dredged material, atmospheric loadings, and groundwater discharges of selected pollutants for selected drainage areas. In addition, an inventory of DEP Confirmed Hazardous Waste Sites located within 500 feet of a surface water body draining to the Massachusetts Bays was compiled. Sediment data for harbors and the bays were reviewed in an effort to identify locations where levels of contaminants were elevated and could represent in-place sediment contaminant sources.

5.2 Runoff from Urban and Nonurban Land Areas

Estimates of loadings have been made for each of the five drainage areas. In addition additional calculations are presented for Boston Harbor. These calculations are based on the Menzie-Cura (1991) report prepared for the MWRA.

5.2.1 Runoff to Drainage Areas

Estimates of urban and nonurban runoff were developed for the areas delineated for each of the five drainage areas. The bases for these areas are provided in Section 3 of this report. Estimates of the concentrations of pollutants in the runoff were taken from NOAA's National Coastal Pollutant Discharge Inventory (NCPDI) and are based on data gathered as part of the Nationwide Urban Runoff Program (NURP). Nonpoint source categories in the NCPDI data base included urban storm runoff (CSO and non-CSO), runoff from cropland, runoff from pastures and brushland, and runoff from deciduous, coniferous, and mixed forests with good and poor cover. Although the NCPDI relies on extrapolation rather than upon direct measurements, it is probably the best source of information necessary to estimate runoff in the region.

Data in the NCPDI were reported by drainage basins defined by U.S. Geological Survey (USGS) cataloging units, counties, and unique areas made up by overlaying county lines upon the USGS cataloging units. As described in Section 3, we assigned each of these areas (called HUCOs) to one of our five drainage areas: Merrimack River, North Shore, Boston Harbor, South Shore, or Cape Cod Bay. In some cases, a HUCO straddled the line of our drainage basins. In those instances, we visually estimated the aerial proportion of the HUCO included in each drainage basin. In subsequent calculations, we assumed that runoff was uniform throughout the HUCO. Therefore, we adjusted data on runoff to reflect the proportion of that HUCO included within the drainage area.

Adjusting data proportionally is probably a reasonable approach for estimating most runoff. For areas that include CSOs, however, runoff may be disproportionate between the drainage areas. Specifically, for HUCOs that straddled the North

Shore and Boston Harbor drainage areas, the methods would probably attribute more runoff from CSOs to the North Shore than actually occurs.

The NCPDI used separate methods to calculate runoff from urban and nonurban land-use areas. For urban land, runoff was calculated separately for areas with CSOs and areas without CSOs. For areas with CSOs, estimates of flow were based on the capacity of the wastewater treatment plant. The estimates accounted for design capacity, the age and condition of the system, and the amount of the capacity used to treat sanitary sewage. The estimates did not, however, include actual measurements. MWRA has measured CSO flow and calculated 7.9×10^9 gallons per year from their entire system. The MWRA value is about one third of the value estimated by the NCPDI for Boston Harbor and about one quarter the NCPDI estimate for Boston Harbor and the North Shore combined. Therefore, the loads calculated for CSOs using flow data from the NCPDI are probably over estimates. Despite this shortcoming, we used the NCPDI data for flow.

The NCPDI calculated pollutant loads by multiplying total flow by typical concentrations of pollutants in CSOs. For most contaminants, data were also available for CSOs from the MWRA system (MWRA, 1989; Wallace et al., 1990) (Table 28). For these data, we recalculated loads, using the NCPDI data for flow and the MWRA data for contaminant concentration.

For areas without CSOs, the NCPDI summed daily precipitation for each land-use type. The total annual precipitation for each land-use type was multiplied by a land-use-specific runoff coefficient, and these values were summed. Loads were calculated using mean urban runoff concentrations for different types of land use compiled for the NCPDI from NURP (EPA, 1983) and Stenstrom et al. (1984) in Table 29.

Nonurban runoff was calculated using the Simulator for Water Resources for Rural Basins (SWRRB) which was developed by the U.S. Department of Agriculture's Agricultural Research Service (USDA ARS). SWRRB simulations were performed for each HUCO that contained nonurban land-use types (all HUCOs except the one comprising Suffolk County).

Table 28. Contaminant concentrations reported for MWRA CSOs and the NCPDI.

Concentrations in CSOs Pollutant	Units	NCPDI	MWRA
Total Suspended Solids	mg/l	310	240
Biochemical Oxygen Demand	mg/l	47.5	110
Total Nitrogen	mg/l	5.08	5.8
Total Phosphorus	mg/l	1.07	2.7
Fecal Coliform	cells/100 ml	2.13E+05	
Oil and Grease	mg/l	13.8	
Iron	ug/l	10.5	
Arsenic	ug/l	9.82	
Cadmium	ug/l	8.09	3.5
Chromium	ug/l	103	22
Copper	ug/l	100	74
Lead	ug/l	474	92
Mercury	ug/l	0.673	
Zinc	ug/l	264	217
PCBs	ug/l	0.42	

Table 29. Contaminant concentrations in runoff.

Mean Concentrations in Urban Runoff from NCPDI							
Pollutant		**Units**	**Residential**	**Commercial**	**Industrial**	**Mixed**	**Open**
Total Suspended Solids		mg/l	206	160	143	297	218
Biochemical Oxygen Demand		mg/l	12	12.4	9.5	12.4	2
Total Nitrogen		mg/l	3.64	2.45	2.32	2.51	1.85
Total Phosphorus		mg/l	0.465	0.493	0.539	0.489	0.188
Fecal Coliform							
	Winter	cells/100 ml	7.10E+03	7.10E+03	7.10E+03	7.10E+03	7.10E+03
	Spring - Fall	cells/100 ml	3.20E+04	3.20E+04	3.20E+04	3.20E+04	3.20E+04
Oil and Grease		mg/l	3.89	13.13	7.1	6.23	0
Iron		ug/l	2.73	2.73	2.73	2.73	2.73
Arsenic		ug/l	4.25	4.25	4.25	4.25	4.25
Cadmium		ug/l	1.58	1.58	1.58	1.58	1.58
Chromium		ug/l	8.51	8.51	8.51	8.51	8.51
Copper		ug/l	19.7	19.7	19.7	19.7	19.7
Lead		ug/l	72.8	72.8	72.8	72.8	72.8
Mercury		ug/l	0.5	0.5	0.5	0.5	0.5
Zinc		ug/l	103.7	103.7	103.7	103.7	103.7
PCBs		ug/l	2.96	2.96	2.96	2.96	2.96

Following the recommendation of USDA ARS (1976), runoff of total nitrogen and total phosphorus from nonurban areas was based solely upon inputs from fertilizers. The procedure employed by NCPDI was as follows:

- For each county, determine the tons of nitrogen and phosphorus applied per season.
- Compute the total cropland in each HUCO.
- Compute the amount of nitrogen and phosphorus applied in each HUCO by weighting the amounts according to area of cropland.
- Determine the percent of cropland in each HUCO that is in conservation tillage.
- Compute the runoff of nitrogen and phosphorus discharged in each HUCO by applying different loss rates from conservation and conventional tillage.

Nonurban runoff of metals was calculated using data on concentrations of metals in soils (Shacklette and Boerngen, 1984 for arsenic, chromium, copper, iron, lead, mercury, and zinc; Helsel, 1978 and Lorenz, 1978 for cadmium). The quantity of soil eroded in each HUCO for each season, calculated by SWRRB, was multiplied by the most frequently occurring concentration reported at the closest sampling points to the HUCO.

Loads calculated using the NCPDI are presented in Table 30.

To estimate runoff from areas that drain directly into coastal waters, we arbitrarily assumed that such runoff occurred from land within 0.5 mi of the shore. We estimated the percentage of area within each drainage area that occurred within 0.5 mi of the shore as 0.3% for Merrimack River, 3% for North Shore, 2% for Boston Harbor, 8% for South Shore, and 60% for Cape Cod Bay. Assuming that runoff is uniform, we used these percentages of the values for total runoff to estimate runoff from coastal areas. This procedure ignored differences in land-use practices along the shoreline from those of the entire drainage areas. It also resulted in underestimating inputs from CSOs that drain into coastal waters. These estimates are provided in Table 31. Because we did not estimate river discharges from Cape Cod to Cape Cod Bay, our summary information on flow and runoff from the Cape Cod Drainage Area is based on the entire drainage area and not on the 0.5 mile region from shore.

Table 30. Estimated loads for runoff within each drainage area.

Loads via Runoff Total Drainage Areas	Flow m3/s	Fecal #/100 ml	BOD kg/yr	TSS kg/yr	Nitrogen kg/yr	Phosphorus kg/yr	As kg/yr	Cd kg/yr	Cr kg/yr	Cu kg/yr
Area/Source										
CSO Inputs										
Merrimack River	5.20E-01	3.48E+16	1.80E+06	3.94E+06	9.51E+04	4.42E+04	1.61E+02	5.74E+01	3.61E+02	1.22E+03
North Shore	8.20E-01	5.48E+16	2.85E+06	6.22E+06	1.50E+05	6.96E+04	2.54E+02	9.05E+01	5.68E+02	1.92E+03
Boston Harbor	2.60E+00	1.74E+17	9.02E+06	1.97E+07	4.75E+05	2.20E+05	8.05E+02	2.87E+02	1.80E+03	6.07E+03
South Shore	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cape Cod Bay	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TOTAL	3.94E+00	2.63E+17	1.37E+07	2.98E+07	7.20E+05	3.34E+05	1.22E+03	4.35E+02	2.73E+03	9.20E+03
NonCSO Inputs										
Merrimack River	9.45E+00	2.66E+16	2.14E+06	3.20E+07	4.91E+05	7.47E+04	1.18E+03	3.28E+02	1.63E+03	7.66E+03
North Shore	6.47E+00	1.98E+16	1.51E+06	2.27E+07	3.48E+05	5.30E+04	8.35E+02	2.32E+02	1.16E+03	5.42E+03
Boston Harbor	9.87E+00	4.76E+16	3.74E+06	5.61E+07	8.61E+05	1.31E+05	2.07E+03	5.73E+02	2.86E+03	1.34E+04
South Shore	1.19E+00	5.68E+15	4.50E+05	6.75E+06	1.03E+05	1.58E+04	2.49E+02	6.90E+01	3.44E+02	1.62E+03
Cape Cod	3.44E-01	1.59E+15	1.30E+05	1.96E+06	3.00E+04	4.55E+03	7.20E+01	2.00E+01	9.95E+01	4.66E+02
TOTAL	2.73E+01	1.01E+17	7.97E+06	1.19E+08	1.83E+06	2.79E+05	4.40E+03	1.22E+03	6.09E+03	2.86E+04
NonUrban										
Merrimack River	6.25E+00	0.00E+00	2.09E+05	3.22E+07	1.64E+05	8.40E+03	5.15E+02	1.29E+01	1.44E+03	6.60E+02
North Shore	2.60E+00	0.00E+00	2.99E+04	1.12E+07	3.09E+04	2.10E+03	1.79E+02	4.47E+00	7.81E+02	3.34E+02
Boston Harbor	1.03E+00	0.00E+00	2.09E+03	1.69E+06	1.06E+04	1.17E+03	1.15E+01	6.74E-01	5.06E+01	2.53E+01
South Shore	1.22E+00	0.00E+00	2.14E+02	3.46E+05	1.07E+02	1.07E+00	2.25E+00	1.39E-01	1.04E+01	5.20E+00
Cape Cod Bay	1.23E-02	0.00E+00	4.55E+01	7.65E+03	1.16E+03	1.40E+02	4.97E-02	3.08E-03	1.53E-01	7.65E-02
TOTAL	1.11E+01	0.00E+00	2.41E+05	4.54E+07	2.07E+05	1.18E+04	7.08E+02	1.82E+01	2.28E+03	1.02E+03
Total										
Merrimack River	1.62E+01	6.14E+16	4.15E+06	6.81E+07	7.50E+05	1.27E+05	1.85E+03	3.98E+02	3.43E+03	9.54E+03
North Shore	9.90E+00	7.46E+16	4.39E+06	4.01E+07	5.29E+05	1.25E+05	1.27E+03	3.27E+02	2.51E+03	7.67E+03
Boston Harbor	1.35E+01	2.21E+17	1.28E+07	7.75E+07	1.35E+06	3.52E+05	2.88E+03	8.61E+02	4.71E+03	1.95E+04
South Shore	2.41E+00	5.68E+15	4.50E+05	7.10E+06	1.03E+05	1.58E+04	2.51E+02	6.91E+01	3.55E+02	1.62E+03
Cape Cod	3.56E-01	1.59E+15	1.30E+05	1.96E+06	3.12E+04	4.69E+03	7.20E+01	2.00E+01	9.97E+01	4.66E+02
TOTAL	**4.24E+01**	**3.65E+17**	**2.19E+07**	**1.95E+08**	**2.76E+06**	**6.25E+05**	**6.33E+03**	**1.68E+03**	**1.11E+04**	**3.88E+04**

Loads via Runoff Total Drainage Areas	Fe kg/yr	Pb kg/yr	Hg kg/yr	Zn kg/yr	Oil kg/yr	PCBs kg/yr
Area/Source						
CSO Inputs						
Merrimack River	1.72E+05	1.51E+03	1.11E+01	3.56E+03	2.26E+05	6.83E+00
North Shore	2.71E+05	2.38E+03	1.74E+01	5.62E+03	3.57E+05	1.08E+01
Boston Harbor	8.58E+05	7.54E+03	5.50E+01	1.78E+04	1.13E+06	3.41E+01
South Shore	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cape Cod Bay	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TOTAL	1.30E+06	1.14E+04	8.35E+01	2.70E+04	1.71E+06	5.17E+01
NonCSO Inputs						
Merrimack River	5.78E+05	3.23E+04	1.78E+01	3.59E+04	1.42E+06	0.00E+00
North Shore	4.09E+05	2.30E+04	1.26E+01	2.54E+04	1.01E+06	0.00E+00
Boston Harbor	1.01E+06	5.67E+04	3.11E+01	6.30E+04	2.50E+06	0.00E+00
South Shore	1.22E+05	6.82E+03	3.75E+00	7.57E+03	2.93E+05	0.00E+00
Cape Cod	3.52E+04	1.98E+03	1.09E+00	2.19E+03	8.18E+04	0.00E+00
TOTAL	2.16E+06	1.21E+05	6.64E+01	1.34E+05	5.30E+06	0.00E+00
NonUrban						
Merrimack River	6.60E+05	4.82E+02	3.22E-03	1.45E+03	0.00E+00	0.00E+00
North Shore	3.34E+05	1.68E+02	1.12E-03	5.03E+02	0.00E+00	0.00E+00
Boston Harbor	2.53E+04	2.44E+01	1.69E-04	7.58E+01	0.00E+00	0.00E+00
South Shore	5.20E+03	3.46E+00	3.46E-05	1.56E+01	0.00E+00	0.00E+00
Cape Cod Bay	1.15E+02	7.65E-02	3.82E-07	1.30E-01	0.00E+00	0.00E+00
TOTAL	1.02E+06	6.78E+02	4.54E-03	2.04E+03	0.00E+00	0.00E+00
Total						
Merrimack River	1.41E+06	3.43E+04	2.88E+01	4.09E+04	1.64E+06	6.83E+00
North Shore	1.01E+06	2.55E+04	3.00E+01	3.16E+04	1.37E+06	1.08E+01
Boston Harbor	1.90E+06	6.42E+04	8.62E+01	8.08E+04	3.63E+06	3.41E+01
South Shore	1.27E+05	6.83E+03	3.75E+00	7.59E+03	2.93E+05	0.00E+00
Cape Cod	3.53E+04	1.98E+03	1.09E+00	2.19E+03	8.18E+04	0.00E+00
TOTAL	**4.48E+06**	**1.33E+05**	**1.50E+02**	**1.63E+05**	**7.02E+06**	**5.17E+01**

Table 31. Estimated loads for runoff within 0.5 mile of coastline.

Loads via Runoff Coastal Area (0.5 miles)	Flow m3/s	Fecal #/100 ml	BOD kg/yr	TSS kg/yr	Nitrogen kg/yr	Phosphorus kg/yr	As kg/yr	Cd kg/yr	Cr kg/yr	Cu kg/yr
Drainage Area										
Merrimack River	4.87E-02	1.84E+14	1.24E+04	2.04E+05	2.25E+03	3.82E+02	6.00E+00	1.00E+00	1.00E+01	2.90E+01
North Shore	2.97E-01	2.24E+15	1.32E+05	1.20E+06	1.59E+04	3.74E+03	3.80E+01	1.00E+01	7.50E+01	2.30E+02
Boston Harbor	2.70E-01	4.43E+15	2.55E+05	1.55E+06	2.69E+04	7.05E+03	5.80E+01	1.70E+01	9.40E+01	3.90E+02
South Shore	1.93E-01	4.55E+14	3.60E+04	5.68E+05	8.27E+03	1.26E+03	2.00E+01	6.00E+00	2.80E+01	1.30E+02
Cape Cod	2.14E-01	9.54E+14	7.82E+04	1.18E+06	1.87E+04	2.82E+03	4.30E+01	1.20E+01	6.00E+01	2.80E+02
TOTAL	**1.02E+00**	**8.26E+15**	**5.14E+05**	**4.70E+06**	**7.20E+04**	**1.52E+04**	**1.65E+02**	**4.60E+01**	**2.67E+02**	**1.06E+03**

Loads via Runoff Coastal Area (0.5 miles)	Fe kg/yr	Pb kg/yr	Hg kg/yr	Zn kg/yr	Oil kg/yr	PCBs kg/yr
Drainage Area						
Merrimack River	4.23E+03	1.03E+02	0.00E+00	1.23E+02	4.93E+03	0.00E+00
North Shore	3.04E+04	7.65E+02	1.00E+00	9.47E+02	4.10E+04	0.00E+00
Boston Harbor	3.79E+04	1.29E+03	2.00E+00	1.62E+03	7.26E+04	1.00E+00
South Shore	1.02E+04	5.46E+02	0.00E+00	6.07E+02	2.34E+04	0.00E+00
Cape Cod	2.12E+04	1.19E+03	1.00E+00	1.32E+03	4.91E+04	0.00E+00
TOTAL	**1.04E+05**	**3.89E+03**	**4.00E+00**	**4.61E+03**	**1.91E+05**	**1.00E+00**

5.2.2 CSOs and Stormwater Discharges to Boston Harbor

This section of the report presents calculations made by Menzie-Cura (1991) for the MWRA. We estimated urban runoff to Boston Harbor in two ways: The first involved using information developed for MWRA by CH2M Hill (1989). The second involved applying the NURP model to the Boston Harbor area. For Quincy Bay, recently discovered problems with storm-drain contamination may result in loadings being underestimated.

CH2M Hill Study

Estimates of pollutant loading to Boston Harbor from CSOs and storm drains are from the Facilities Plan (CH2M Hill, 1989). The study area for the Facilities Plan includes the Dorchester Bay Basin, the Neponset Estuary Basin, the Inner Harbor Basin, and the Quincy Bay/Outer Harbor Basin, which comprise the North Harbor as defined for the present analysis. The Alewife/Mystic Basin, the Upper Charles River Basin, and the Lower Charles River Basin are other basins for which loadings were estimated by CH2M Hill; these are not included in the estimates of direct loading to Boston Harbor since their contribution is included as tributary sources. None of the CSO or storm drain load in these estimates directly enters the South Harbor.

Annual pollutant loadings due to CSOs and storm drains were calculated by CH2M Hill using a sewer model that was calibrated with measured concentrations and flow rates taken during wet and dry conditions during the spring and summer of 1988 (CH2M HILL Tech. Mem. 3-10).

The Facilities Plan provides estimates of dry weather overflow (DWO), and wet weather overflow from CSOs and storm drains (SWO). The DWO estimate was subtracted from the sum of the CSO and SWO estimates to obtain the net discharge associated with storm events.

Estimates of loads via CSOs and stormwater to the northern Boston Harbor are provided in Table 32. These estimates were taken from the facilities plan authored by CH2M Hill and are presented according to their selected basins: Dorchester Bay, Neponset Estuary, Inner Harbor, and Quincy Bay/Outer Harbor. All these basins are contained within North Harbor as defined for the present analysis. No estimates of CSO loadings were available for the South Harbor.

Total annual loading to North Harbor is estimated to be 8,855 mt total suspended solids, 3,905 mt BOD, 20 kg TKN, 96 kg phosphorus, 4,278 kg copper, 354 kg lead, 854 kg zinc, and 4.92E+16 counts fecal coliform.

Table 32. Stormwater and CSO annual load summary for northern Boston Harbor.

Stormwater and CSO Annual Load Summary for North Harbor Drainage

North Harbor Drainage Basin	BOD (mton)	TSS (mton)	TKN (kg)	TP (kg)	Cu (kg)	Pb (kg)	Zn (kg)	FCB (count)
Dorchester Bay Basin								
CSO	226	432	16	5	242	302	660	2.36E+15
Stormwater in Storm Sewers	30	72	3	1	63	51	193	2.82E+14
Total stormwater in sewers	255	504	20	5	305	354	854	2.65E+15
Neponset Estuary Basin								
CSO	9	15	1	0	10	12	29	1.86E+14
Stormwater in Storm Sewers	195	474	22	5	415	339	1,277	1.86E+14
Total stormwater in sewers	205	489	23	5	425	351	1,305	3.73E+14
Inner Harbor Basin								
CSO	2,656	5,983	136	67	2,251	3,235	6,634	4.14E+16
Stormwater in Storm Sewers	399	966	45	10	848	691	2,605	3.82E+15
Total stormwater in sewers	3,055	6,950	181	76	3,099	3,926	9,239	4.52E+16
Quincy Bay/Outer Harbor								
CSO	290	669	15	7	235	344	700	0.00E+00
Stormwater in Storm Sewers	100	244	11	2	214	175	658	9.55E+14
Total stormwater in sewers	390	913	26	10	449	518	1,358	9.55E+14
Boston Harbor stormwater in sewers	3,905	8,855	249	96	4,278	5,149	12,756	4.92E+16

Source: Combined Sewer Overflow Facilities Plan Executive Summary, MWRA 1989.

We estimated pollutant loading to Boston Harbor due to direct urban runoff from the cities and towns within the coastal drainage basin using the methodology adopted by the EPA Nonpoint Source Branch (described in the National Urban Runoff Program Report available from EPA Office Of Water). The NURP methodology is a stochastic approach. It models the episodic rainfall events which cause urban runoff. In the model, pollutant concentration in runoff derives from land use category and rainfall event statistics. The NURP approach calculates loadings from total rainfall and the area within each land use category.

Event statistics were calculated from long-term, hourly rainfall records from four gauging stations in eastern Massachusetts. Mean and coefficient of variation for storm duration, intensity, volume, and time between storms were calculated using SYNOP, a computer program developed specifically to provide input for the NURP analysis. Pollutant concentration and runoff coefficient for each land use type were taken from the NURP report based on the event statistics provided by SYNOP. The area of each land-use category within the cities and towns bordering Boston Harbor was from Hruby et al. (1988) and is based on the land use maps of MacConnell et al. (1985). These areas include only the portion of cities and towns within the coastal drainage basin (Table 33).

Pollutant loadings by land-use category were calculated by multiplying the mean concentration by the runoff coefficient and an annual rainfall of 44 inches. Total loading was calculated by summing over land-use categories.

Loadings are estimated for total suspended solids, BOD and COD combined, total phosphorous, total nitrogen, TKN, copper, lead, and zinc (Table 34). Estimates of loadings for other pollutants are not validated sufficiently using the NURP methodology to allow their presentation.The estimated loadings for lead, 6,585 kg for North Harbor and 1927 kg for South Harbor, may be higher than present loadings due to decreased use of leaded gasoline since the time the NURP methodology was developed. The NURP estimate is much lower than the estimated lead loading reported by Hruby et al. (1988), which is roughly 60,000 kg/yr to North and South Harbors combined. Hruby et al. relied on the methodology of Midwest Research Institute (McElroy et al., 1976), using lead loadings which are likely outdated.

Table 33. Summary of land use in the coastal drainage area around Boston Harbor.

Summary of Coastal Drainage Basin Land Use Areas	Residential	Commercial	Industrial	Transportation	Open	Runway	Total
North Harbor Drainage (acres)							
Boston	2,670	1,371	413	1,854	1,643	0	7,951
Logan Airport	0	0	0	0	837	806	1,643
Chelsea	349	97	231	56	86	0	819
Everett	150	0	0	0	16	0	166
Winthrop	762	18	8	199	340	0	1,327
South Harbor Drainage (acres)							
Hingham	1,355	90	134	36	1,781	0	3,396
Hull	1,049	58	14	16	645	0	1,782
Quincy	1,712	106	140	56	1,153	0	3,167
Weymouth	313	60	34	0	230	0	637

Source: Land Use in the Coastal Drainage Area in and around Boston Harbor
Hruby, T., S. Cotter, K. Barnes, Mass. Audubon Society, 1988.
(Based on land use maps prepared by W.P. MacConnell, University of Massachusetts Amherst)

Table 34. Summary of annual loads to Boston Harbor using NURP data.

Summary of Annual Pollutant Loads Using NURP data	TSS (mton)	BOD+COD (mton)	t-P (kg)	t-N (kg)	TKN (kg)	Copper (kg)	Lead (kg)	Zinc (kg)
North Harbor Drainage Basin								
Boston	3,252	1,819	6,248	14,362	30,824	802	4,076	4,967
Chelsea	619	260	1,087	2,629	5,199	139	562	778
Everett	38	19	85	178	391	9	37	42
Winthrop	345	194	714	1,521	3,376	83	438	466
Total	4,254	2,292	8,134	18,690	39,790	1,033	5,113	6,253
Logan Airport	794	529	1,514	3,027	7,134	203	1,472	1,291
South Harbor Drainage Basin								
Hingham	757	347	1,423	3,481	7,102	163	657	993
Hull	356	181	742	1,702	3,631	81	335	462
Quincy	839	395	1,636	3,831	7,948	188	773	1,069
Weymouth	183	87	352	855	1,754	42	162	249
Total	2,135	1,010	4,153	9,869	20,435	474	1,927	2,773

5.3 Discharges from Coastal Rivers

The major coastal rivers discharging to Massachusetts Bay are presented in Section 6 along with estimates of annual flow. We have estimated loadings associated with these rivers as another method for estimating loadings associated with point and nonpoint sources within the various drainage areas. The approach involved developing estimates of pollutant concentrations near the mouths of the rivers and multiplying these estimates by annual river flows presented in Section 3 of this report.

Estimates of pollutant concentrations were developed using a combination of measurements made by the Massachusetts DWPC along with literature values on typical levels of chemicals in river water. The latter data were used in several cases where the measurements did not seem to be correct in our opinion or where data were lacking.

5.3.1 Water Quality Data for Massachusetts Rivers

Water quality data were available at or near the mouths of several rivers within the Massachusetts Bay drainage areas:

- Merrimack River. Data were available for two stations sampled in 1986, one at the Routes 1 and 1A bridge in Newburyport (River Mile 3.0) and one near the Essex-Merrimack Bridge in Amesbury (River Mile 5.2). Data were also available for 1989, but the farthest downstream station was at the Route 25 bridge in Haverhill (River Mile 18.5).

- Ipswich River. Data were available for two stations sampled in 1985, one at Green Street in Ipswich (River Mile 4.2) and one at the GTE-Sylvania Dam in Ipswich (River Mile 4.5).

- Parker River. Data were available for one station sampled in 1984, the Route 1 bridge in Newburyport (River Mile 4.9).

- Mystic River. Data were available for one station sampled in 1983-1986, near the confluence with the Island End River.

- Chelsea River. Data were available for one station sampled in 1983-1986, at Meridian Street (River Mile 0.2).

- Charles River. Data were available for one station sample in 1982-1986, just downstream of the Charlestown Bridge.

- Neponset River. Data were available for one station sampled in 1984-1986, just upstream from the Neponset Bridge in Boston.

- North River. Data were available for one station sampled in 1989, at the Bridge Street bridge in Norwell (River Mile 4.2). Only conventional parameters were measured.

Summaries of the water quality data for the rivers are provided in Tables 35 through 43.

Table 35. Water quality data for total suspended solids.

River Water Quality TSS Concentrations (mg/l) River	Number Stations	Number Years	Number Observ.	Mean	Min	Max	References
Merrimack Drainage							
Merrimack River	3	2	10	6.80	3.50	19.00	DEQE,1988;DEP,1990a
North Shore Drainage							
Ipswich River	2	1	5	3.70	3.00	6.50	DEQE,1986a
Essex River							
Rowley River							
Parker River	1	1	2	17.00	14.00	20.00	DEQE,1986b
Annisquam River							
Bass River							
North River							
Danvers River							
Crane River							
Pines River							
Saugus River							
Boston Harbor Drainage							
Mystic River	1	5	30	15.10	1.00	46.00	DEQE,1982,1983,1984,1986c,1987
Chelsea River	1	3	21	13.37	4.00	56.00	DEQE,1984,1986c,1987
Charles River	1	5	31	11.26	0.00	30.00	DEQE,1982,1983,1984,1986c,1987
Neponset River	1	3	18	16.61	<2	31.00	DEQE,1984,1986c,1987
Weymouth Fore River							
Weymouth Back River							
Weir River							
South Shore Drainage							
South River							
North River	1	1	3	3.00	2.00	4.50	DEP,1990b
Green Harbor River							
Jones River							
Town Brook							
Eel River							
Herring River							
Beaver Brook Dam							
Mean for rivers		10.86					
Mean for all measurements		12.59					

Table 36. Water quality data for biochemical oxygen demand.

River Water Quality BOD Concentrations (mg/l) River	Number Stations	Number Years	Number Observ.	Mean	Min	Max	References
Merrimack Drainage							
Merrimack River	3	2	8	1.61	0.00	2.40	DEQE,1988;DEP,1990a
North Shore Drainage							
Ipswich River	2	1	5	2.64	0.90	4.80	DEQE,1986a
Essex River							
Rowley River							
Parker River	1	1	2	3.10	1.20	5.00	DEQE,1986b
Annisquam River							
Bass River							
North River							
Danvers River							
Crane River							
Pines River							
Saugus River							
Boston Harbor Drainage							
Mystic River							
Chelsea River	1	2	8	4.58	1.20	8.70	DEQE,1982,1983
Charles River							
Neponset River							
Weymouth Fore River							
Weymouth Back River							
Weir River							
South Shore Drainage							
South River							
North River							DEP,1990b
Green Harbor River							
Jones River							
Town Brook							
Eel River							
Herring River							
Beaver Brook Dam							
Mean for rivers		3.98					
Mean for all measurements		3.00					

Table 37. Water quality data for nitrogen.

River Water Quality Nitrogen Concentrations (mg/l) River	Number Stations	Number Years	Number Observ.	Mean	Min	Max	References
Merrimack Drainage							
Merrimack River	3	2	6	1.44	0.87	2.03	DEQE,1988;DEP,1990a
North Shore Drainage							
Ipswich River	2	1	5	1.49	0.97	3.00	DEQE,1986a
Essex River							
Rowley River							
Parker River	1	1	2	2.01	1.51	2.50	DEQE,1986b
Annisquam River							
Bass River							
North River							
Danvers River							
Crane River							
Pines River							
Saugus River							
Boston Harbor Drainage							
Mystic River	1	5	31	1.59	0.50	2.80	DEQE,1982,1983,1984,1986c,1987
Chelsea River	1	3	22	2.85	1.07	6.61	DEQE,1984,1986c,1987
Charles River	1	5	31	1.63	0.44	3.11	DEQE,1982,1983,1984,1986c,1987
Neponset River	1	3	19	1.77	0.72	4.11	DEQE,1984,1986c,1987
Weymouth Fore River							
Weymouth Back River							
Weir River							
South Shore Drainage							
South River							
North River	1	1	3	1.71	1.53	1.90	DEP,1990b
Green Harbor River							
Jones River							
Town Brook							
Eel River							
Herring River							
Beaver Brook Dam							
Mean for rivers		1.81					
Mean for all measurements		1.86					

Table 38. Water quality data for phosphorous.

River Water Quality Phosphorus Concentrations (mg/l) River	Number Stations	Number Years	Number Observ.	Mean	Min	Max	References
Merrimack Drainage							
Merrimack River	3	2	11	0.14	0.09	0.20	DEQE,1988;DEP,1990a
North Shore Drainage							
Ipswich River	2	1	5	0.09	0.07	0.11	DEQE,1986a
Essex River							
Rowley River							
Parker River	1	1	1	0.15	0.14	0.16	DEQE,1986b
Annisquam River							
Bass River							
North River							
Danvers River							
Crane River							
Pines River							
Saugus River							
Boston Harbor Drainage							
Mystic River	1	5	31	0.17	0.04	0.29	DEQE,1982,1983,1984,1986c,1987
Chelsea River	1	3	27	0.20	0.08	0.36	DEQE,1984,1986c,1987
Charles River	1	5	31	0.17	0.06	0.39	DEQE,1982,1983,1984,1986c,1987
Neponset River	1	3	19	0.18	0.11	0.28	DEQE,1984,1986c,1987
Weymouth Fore River							
Weymouth Back River							
Weir River							
South Shore Drainage							
South River							
North River	1	1	3	0.15	0.13	0.17	DEP,1990b
Green Harbor River							
Jones River							
Town Brook							
Eel River							
Herring River							
Beaver Brook Dam							
Mean for rivers		0.16					
Mean for all measurements		0.18					

Table 39. Water quality data for cadmium.

River Water Quality Cadmium Concentrations (mg/l) River	Number Stations	Number Years	Number Observ.	Mean	Min	Max	References
Merrimack Drainage							
Merrimack River	3	2	10	0.001	0.000	0.004	DEQE,1988;DEP,1990a
North Shore Drainage							
Ipswich River	1	1	1	0.000	0.000	0.000	DEQE,1986a
Essex River							
Rowley River							
Parker River	1	1	1	0.000	0.000	0.000	DEQE,1986b
Annisquam River							
Bass River							
North River							
Danvers River							
Crane River							
Pines River							
Saugus River							
Boston Harbor Drainage							
Mystic River	1	4	20	0.020	0.000	0.070	DEQE,1982,1983,1984,1986c
Chelsea River	1	2	13	0.020	0.000	0.060	DEQE,1984,1986c
Charles River	1	4	21	0.018	0.000	0.070	DEQE,1982,1983,1984,1986c
Neponset River	1	2	12	0.021	0.000	0.060	DEQE,1984,1986c
Weymouth Fore River							
Weymouth Back River							
Weir River							
South Shore Drainage							
South River							
North River							DEP,1990b
Green Harbor River							
Jones River							
Town Brook							
Eel River							
Herring River							
Beaver Brook Dam							
Mean for rivers		0.011					
Mean for all measurements		0.017					

Values entered as 0 are less than detection limits of .001-.02 mg/l

Table 40. Water quality data for chromium.

River Water Quality Chromium Concentrations (mg/l) River	Number Stations	Number Years	Number Observ.	Mean	Min	Max	References
Merrimack Drainage							
Merrimack River	2	1	4	0.00	0.00	0.00	DEQE,1988;DEP,1990a
North Shore Drainage							
Ipswich River	1	1	1	0.00	0.00	0.00	DEQE,1986a
Essex River							
Rowley River							
Parker River	1	1	1	0.01	0.01	0.01	DEQE,1986b
Annisquam River							
Bass River							
North River							
Danvers River							
Crane River							
Pines River							
Saugus River							
Boston Harbor Drainage							
Mystic River	1	4	23	0.03	0.00	0.06	DEQE,1982,1983,1984,1986c
Chelsea River	1	2	14	0.02	0.00	0.03	DEQE,1984,1986c
Charles River	1	4	23	0.02	0.00	0.06	DEQE,1982,1983,1984,1986c
Neponset River	1	2	13	0.02	0.00	0.04	DEQE,1984,1986c
Weymouth Fore River							
Weymouth Back River							
Weir River							
South Shore Drainage							
South River							
North River							DEP,1990b
Green Harbor River							
Jones River							
Town Brook							
Eel River							
Herring River							
Beaver Brook Dam							
Mean for rivers		0.01					
Mean for all measurements		0.02					

Values entered as 0 are less than the detection limit of 0.02 mg/l.

Table 41. Water quality data for copper.

River Water Quality Copper Concentrations (mg/l) River	Number Stations	Number Years	Number Observ.	Mean	Min	Max	References
Merrimack Drainage							
Merrimack River	3	2	11	0.002	<0.002	0.019	DEQE,1988;DEP,1990a
North Shore Drainage							
Ipswich River	1	1	1	<0.002	<0.002	<0.002	DEQE,1986a
Essex River							
Rowley River							
Parker River	1	1	1	0.000	0.000	0.000	DEQE,1986b
Annisquam River							
Bass River							
North River							
Danvers River							
Crane River							
Pines River							
Saugus River							
Boston Harbor Drainage							
Mystic River	1	4	23	0.070	<0.02	0.150	DEQE,1982,1983,1984,1986c
Chelsea River	1	2	14	0.068	<0.02	0.250	DEQE,1984,1986c
Charles River	1	4	23	0.054	<0.02	0.240	DEQE,1982,1983,1984,1986c
Neponset River	1	2	14	0.089	<0.02	0.260	DEQE,1984,1986c
Weymouth Fore River							
Weymouth Back River							
Weir River							
South Shore Drainage							
South River							
North River							DEP,1990b
Green Harbor River							
Jones River							
Town Brook							
Eel River							
Herring River							
Beaver Brook Dam							
Mean for rivers		0.129					
Mean for all measurements		0.058					

Table 42. Water quality data for lead.

River Water Quality Lead Concentrations (mg/l) River	Number Stations	Number Years	Number Observ.	Mean	Min	Max	References
Merrimack Drainage							
Merrimack River	3	2	11	0.01	<0.02	0.03	DEQE,1988;DEP,1990a
North Shore Drainage							
Ipswich River	1	1	1	<0.02	<0.02	<0.02	DEQE,1986a
Essex River							
Rowley River							
Parker River	1	1	1	0.06	0.06	0.06	DEQE,1986b
Annisquam River							
Bass River							
North River							
Danvers River							
Crane River							
Pines River							
Saugus River							
Boston Harbor Drainage							
Mystic River	1	4	23	0.22	<0.04	0.40	DEQE,1982,1983,1984,1986c
Chelsea River	1	2	14	0.19	<0.04	0.46	DEQE,1984,1986c
Charles River	1	4	23	0.17	<0.04	0.33	DEQE,1982,1983,1984,1986c
Neponset River	1	2	13	0.19	<0.04	0.37	DEQE,1984,1986c
Weymouth Fore River							
Weymouth Back River							
Weir River							
South Shore Drainage							
South River							
North River							
Green Harbor River							
Jones River							
Town Brook							
Eel River							
Herring River							
Beaver Brook Dam							
Mean for rivers		0.12					
Mean for all measurements		0.168					

Table 43. Water quality data for zinc.

River Water Quality Zinc Concentrations (mg/l) River	Number Stations	Number Years	Number Observ.	Mean	Min	Max	References
Merrimack Drainage							
Merrimack River	3	2	11	0.004	0.000	0.023	DEQE,1988;DEP,1990a
North Shore Drainage							
Ipswich River	1	1	1	0.000	0.000	0.000	DEQE,1986a
Essex River							
Rowley River							
Parker River	1	1	2	0.040	0.020	0.060	DEQE,1986b
Annisquam River							
Bass River							
North River							
Danvers River							
Crane River							
Pines River							
Saugus River							
Boston Harbor Drainage							
Mystic River	1	4	23	0.037	0.000	0.100	DEQE,1982,1983,1984,1986c
Chelsea River	1	2	14	0.021	0.000	0.070	DEQE,1984,1986c
Charles River	1	4	23	0.048	0.000	0.450	DEQE,1982,1983,1984,1986c
Neponset River	1	2	13	0.069	0.000	0.210	DEQE,1984,1986c
Weymouth Fore River							
Weymouth Back River							
Weir River							
South Shore Drainage							
South River							
North River							DEP,1990b
Green Harbor River							
Jones River							
Town Brook							
Eel River							
Herring River							
Beaver Brook Dam							
Mean for rivers		0.031					
Mean for all measurements		0.038					

Values entered as 0 are less than detection limits of 0.03-0.03 mg/l

5.3.2 Estimates of Loadings via Major Rivers

Based on an evaluation of the reliability of the data in Tables 35 through 43, we judged that the following water quality parameters could be relied upon for making estimates of loadings from the available measurement data: total suspended solids, biochemical oxygen demand, nitrogen, and phosphorus. The data for metals were not considered entirely reliable because some of the values greatly exceeded levels reported for urban riverine environments and also differed with more recent data gathered by Gordon Wallace of University of Massachusetts at Boston. No data were available for the levels of PAHs in Massachusetts river water.

Based on a review of the literature on metals and PAH levels in rivers of the United States, ranges were developed for estimating loadings of these chemical compounds to Massachusetts Bays via rivers (Table 44). Primary sources of data were Neff (1979), Forstner and Wittman (1981), USGS (1985), USEPA (1983, 1986), Atlas et al. (1986), USPHS (1987), and Menzie et al. (1991).

Table 44. Literature values for ranges of concentrations of selected chemicals in river water.

Chemicals	Range from Literature Review	Value Used
Arsenic	90% < 10 ug/l	10 ug/l
Cadmium	0.01 - 7	1 ug/l
Chromium	1 - 30 ug/l	6 ug/l
Copper		10 ug/l
Lead	1 - 890	1 - 30 ug/l
Zinc	2 - 50,000 ug/l	1 - 30 ug/l
PAHs	10 - 100 ng/l	50 ng/l
PCBs	0.1 - 20 ng/l	1 ng/l
Phthalates	50 - 10,000 ng/l	100 ng/l

Using either the measured values or the ranges in literature values, estimates were made of the loadings via major rivers are provided in Tables 45 through 57.

Table 45. Loadings of total suspended solids via rivers.

River Loads suspended solids	Annual flow rate (m3/sec)	Years of Data	Avg Conc (mg/l)	Conc. Used in Loadings Estimate (mg/l)		Estimated Loadings (Kg/Yr)
Merrimack Drainage						

Merrimack River	243.84	3	7.58	7.58		5.83E+07
				Subtotal =	5.83E+07	
North Shore Drainage						

Ipswich River	6.46	1	3.25	3.25		6.62E+05
Essex River	0.45			*10.50*		1.49E+05
Rowley River	0.48			*10.50*		1.59E+05
Parker River	2.86	2	16.58	16.58		1.50E+06
Annisquam River	0.11			*10.50*		3.64E+04
Bass River	0.07			*10.50*		2.32E+04
North River				*10.50*		0.00E+00
Danvers River	0.59			*10.50*		1.95E+05
Crane River	0.28			*10.50*		9.27E+04
Pines River	0.48			*10.50*		1.59E+05
Saugus River	2.32			*10.50*		7.68E+05
				Subtotal =	3.74E+06	
Boston Harbor Drainage						

Mystic River	3.18	5	11.97	11.97		1.20E+06
Chelsea River		5	15.47	15.47		0.00E+00
Charles River	15.35	5	10.16	10.16		4.92E+06
Neponset River	5.58	6	21.92	21.92		3.86E+06
Weymouth Fore River	6.28	1	5.60	5.60		1.11E+06
Weymouth Back River	4.38	1	9.10	9.10		1.26E+06
Weir River	1.25	1	9.10	9.10		3.59E+05
				Subtotal =	1.27E+07	
South Shore Drainage						

South River	1.15			*10.50*		3.81E+05
North River	3.90	1	5.00	5.00		6.15E+05
Green Harbor River	0.35			*10.50*		1.16E+05
Jones River	1.71			*10.50*		5.65E+05
Town Brook	0.31			*10.50*		1.03E+05
Eel River	0.51			*10.50*		1.69E+05
Herring River	0.37			*10.50*		1.23E+05
Beaver Brook Dam	0.18			*10.50*		5.96E+04
				Subtotal =	2.13E+06	
		Maximum =	21.92		TOTAL =	7.69E+07
		Minimum =	3.25			
		Average =	10.52		% Merrimack =	76%

Table 46. Loadings of biochemical oxygen demand via rivers.

River Loads biochemical oxygen demand	Annual flow rate (m3/sec)	Years of Data	Avg Conc (mg/l)	Conc. Used in Loadings Estimate (mg/l)		Estimated Loadings (Kg/Yr)
Merrimack Drainage						

Merrimack River	243.84	2	1.61E+00	1.61E+00		1.24E+07
				Subtotal =	1.24E+07	
North Shore Drainage						

Ipswich River	6.46	1	2.64E+00	2.64E+00		5.38E+05
Essex River	0.45			3.00E+00		4.26E+04
Rowley River	0.48			3.00E+00		4.54E+04
Parker River	2.86	1	3.10E+00	3.10E+00		2.80E+05
Annisquam River	0.11			3.00E+00		1.04E+04
Bass River	0.07			3.00E+00		6.62E+03
North River				3.00E+00		0.00E+00
Danvers River	0.59			3.00E+00		5.58E+04
Crane River	0.28			3.00E+00		2.65E+04
Pines River	0.48			3.00E+00		4.54E+04
Saugus River	2.32			3.00E+00		2.19E+05
				Subtotal =	1.27E+06	
Boston Harbor Drainage						

Mystic River	3.18			3.00E+00		3.01E+05
Chelsea River		1	4.58E+00	4.58E+00		0.00E+00
Charles River	15.35			3.00E+00		1.45E+06
Neponset River	5.58			3.00E+00		5.28E+05
Weymouth Fore River	6.28			3.00E+00		5.94E+05
Weymouth Back River	4.38			3.00E+00		4.14E+05
Weir River	1.25			3.00E+00		1.18E+05
				Subtotal =	3.41E+06	
South Shore Drainage						

South River	1.15			3.00E+00		1.09E+05
North River	3.90			3.00E+00		3.69E+05
Green Harbor River	0.35			3.00E+00		3.31E+04
Jones River	1.71			3.00E+00		1.62E+05
Town Brook	0.31			3.00E+00		2.93E+04
Eel River	0.51			3.00E+00		4.83E+04
Herring River	0.37			3.00E+00		3.50E+04
Beaver Brook Dam	0.18			3.00E+00		1.70E+04
				Subtotal =	8.02E+05	
		Maximum :	4.58E+00		TOTAL =	1.79E+07
		Minimum =	1.61E+00			
		Average =	2.98E+00		% Merrimack =	69%

Table 47. Loadings of total nitrogen via rivers.

River Loads total nitrogen	Annual flow rate (m3/sec)	Years of Data	Avg Conc (mg/l)	Conc. Used in Loadings Estimate (mg/l)		Estimated Loadings (Kg/Yr)
Merrimack Drainage						

Merrimack River	243.84	3	1.44E+00	1.44E+00		1.11E+07
				Subtotal =	1.11E+07	
North Shore Drainage						

Ipswich River	6.46	1	1.20E+00	1.20E+00		2.43E+05
Essex River	0.45			1.39E+00		1.97E+04
Rowley River	0.48			1.39E+00		2.10E+04
Parker River	2.86	1	2.01E+00	2.01E+00		1.81E+05
Annisquam River	0.11	1	9.13E-01	9.13E-01		3.17E+03
Bass River	0.07			1.39E+00		3.07E+03
North River				1.39E+00		0.00E+00
Danvers River	0.59			1.39E+00		2.59E+04
Crane River	0.28			1.39E+00		1.23E+04
Pines River	0.48			1.39E+00		2.10E+04
Saugus River	2.32			1.39E+00		1.02E+05
				Subtotal =	6.32E+05	
Boston Harbor Drainage						

Mystic River	3.18	5	1.56E+00	1.56E+00		1.56E+05
Chelsea River		6	1.45E+00	1.45E+00		0.00E+00
Charles River	15.35	6	1.57E+00	1.57E+00		7.60E+05
Neponset River	5.58	8	1.82E+00	1.82E+00		3.21E+05
Weymouth Fore River	6.28	2	7.16E-01	1.39E+00		2.75E+05
Weymouth Back River	4.38			1.39E+00		1.92E+05
Weir River	1.25	1	1.43E+00	1.39E+00		5.48E+04
				Subtotal =	1.76E+06	
South Shore Drainage						

South River	1.15			1.39E+00		5.04E+04
North River	3.90	1	1.17E+00	1.17E+00		1.44E+05
Green Harbor River	0.35			1.39E+00		1.53E+04
Jones River	1.71			1.39E+00		7.48E+04
Town Brook	0.31			1.39E+00		1.36E+04
Eel River	0.51			1.39E+00		2.24E+04
Herring River	0.37			1.39E+00		1.62E+04
Beaver Brook Dam	0.18			1.39E+00		7.89E+03
				Subtotal =	3.45E+05	
		Maximum =	2.01E+00		**TOTAL =**	1.38E+07
		Minimum =	7.16E-01			
		Average =	1.39E+00		% Merrimack =	**80%**

Table 48. Loadings of total phosphorus via rivers.

River Loads total phosphorus	Annual flow rate (m3/sec)	Years of Data	Avg Conc (mg/l)	Conc. Used in Loadings Estimate (mg/l)		Estimated Loadings (Kg/Yr)
Merrimack Drainage						

Merrimack River	243.84	3	1.40E-01	1.40E-01		1.08E+06
				Subtotal =	1.08E+06	
North Shore Drainage						

Ipswich River	6.46	1	1.00E-01	1.00E-01		2.04E+04
Essex River	0.45			1.47E-01		2.09E+03
Rowley River	0.48			1.47E-01		2.23E+03
Parker River	2.86			1.47E-01		1.33E+04
Annisquam River	0.11	2	1.30E-01	1.30E-01		4.51E+02
Bass River	0.07			1.47E-01		3.25E+02
North River				1.47E-01		0.00E+00
Danvers River	0.59			1.47E-01		2.74E+03
Crane River	0.28			1.47E-01		1.30E+03
Pines River	0.48			1.47E-01		2.23E+03
Saugus River	2.32			1.47E-01		1.08E+04
				Subtotal =	5.57E+04	
Boston Harbor Drainage						

Mystic River	3.18	5	1.90E-01	1.90E-01		1.91E+04
Chelsea River		6	1.80E-01	1.80E-01		0.00E+00
Charles River	15.35	6	1.80E-01	1.80E-01		8.71E+04
Neponset River	5.58	8	1.90E-01	1.90E-01		3.34E+04
Weymouth Fore River	6.28	2	8.00E-02	8.00E-02		1.58E+04
Weymouth Back River	4.38	1	1.10E-01	1.10E-01		1.52E+04
Weir River	1.25			1.47E-01		5.79E+03
				Subtotal =	1.76E+05	
South Shore Drainage						

South River	1.15			1.47E-01		5.33E+03
North River	3.90	1	1.70E-01	1.70E-01		2.09E+04
Green Harbor River	0.35			1.47E-01		1.62E+03
Jones River	1.71			1.47E-01		7.92E+03
Town Brook	0.31			1.47E-01		1.44E+03
Eel River	0.51			1.47E-01		2.36E+03
Herring River	0.37			1.47E-01		1.72E+03
Beaver Brook Dam	0.18			1.47E-01		8.34E+02
				Subtotal =	4.21E+04	
		Maximum :	1.90E-01		TOTAL =	1.35E+06
		Minimum =	8.00E-02			
		Average =	1.47E-01		% Merrimack =	80%

Table 49. Loadings of total PAHs via rivers.

River Loads total PAHs	Annual flow rate (m3/sec)	Conc. Used in Loadings Estimate (1) (mg/l)		Lower Estimated Loadings (Kg/Yr)
Merrimack Drainage				
Merrimack River	243.84	5.00E-05		3.84E+02
		Subtotal =	3.84E+02	
North Shore Drainage				
Ipswich River	6.46	5.00E-05		1.02E+01
Essex River	0.45	5.00E-05		7.10E-01
Rowley River	0.48	5.00E-05		7.57E-01
Parker River	2.86	5.00E-05		4.51E+00
Annisquam River	0.11	5.00E-05		1.73E-01
Bass River	0.07	5.00E-05		1.10E-01
North River		5.00E-05		0.00E+00
Danvers River	0.59	5.00E-05		9.30E-01
Crane River	0.28	5.00E-05		4.42E-01
Pines River	0.48	5.00E-05		7.57E-01
Saugus River	2.32	5.00E-05		3.66E+00
		Subtotal =	2.22E+01	
Boston Harbor Drainage				
Mystic River	3.18	5.00E-05		5.01E+00
Chelsea River		5.00E-05		0.00E+00
Charles River	15.35	5.00E-05		2.42E+01
Neponset River	5.58	5.00E-05		8.80E+00
Weymouth Fore River	6.28	5.00E-05		9.90E+00
Weymouth Back River	4.38	5.00E-05		6.91E+00
Weir River	1.25	5.00E-05		1.97E+00
		Subtotal =	5.68E+01	
South Shore Drainage				
South River	1.15	5.00E-05		1.81E+00
North River	3.90	5.00E-05		6.15E+00
Green Harbor River	0.35	5.00E-05		5.52E-01
Jones River	1.71	5.00E-05		2.69E+00
Town Brook	0.31	5.00E-05		4.89E-01
Eel River	0.51	5.00E-05		8.04E-01
Herring River	0.37	5.00E-05		5.83E-01
Beaver Brook Dam	0.18	5.00E-05		2.84E-01
		Subtotal =	1.34E+01	
			TOTAL =	4.77E+02
			% Merrimack =	81%

1. A value of 50 ng/l was selected for PAH concentration in surface water. This value falls within the range of 10 to 100 ng/l reported by Menzie (1990) for urban river systems.

Table 50. Loadings of total PCBs via rivers.

River Loads PCBs	Annual flow rate (m3/sec)	Conc. Used in Loadings Estimate (1) (mg/l)		Lower Estimated Loadings (Kg/Yr)
Merrimack Drainage				
Merrimack River	243.84	1.00E-06		7.69E+00
		Subtotal =	7.69E+00	
North Shore Drainage				
Ipswich River	6.46	1.00E-06		2.04E-01
Essex River	0.45	1.00E-06		1.42E-02
Rowley River	0.48	1.00E-06		1.51E-02
Parker River	2.86	1.00E-06		9.02E-02
Annisquam River	0.11	1.00E-06		3.47E-03
Bass River	0.07	1.00E-06		2.21E-03
North River		1.00E-06		0.00E+00
Danvers River	0.59	1.00E-06		1.86E-02
Crane River	0.28	1.00E-06		8.83E-03
Pines River	0.48	1.00E-06		1.51E-02
Saugus River	2.32	1.00E-06		7.32E-02
		Subtotal =	4.45E-01	
Boston Harbor Drainage				
Mystic River	3.18	1.00E-06		1.00E-01
Chelsea River		1.00E-06		0.00E+00
Charles River	15.35	1.00E-06		4.84E-01
Neponset River	5.58	1.00E-06		1.76E-01
Weymouth Fore River	6.28	1.00E-06		1.98E-01
Weymouth Back River	4.38	1.00E-06		1.38E-01
Weir River	1.25	1.00E-06		3.94E-02
		Subtotal =	1.14E+00	
South Shore Drainage				
South River	1.15	1.00E-06		3.63E-02
North River	3.90	1.00E-06		1.23E-01
Green Harbor River	0.35	1.00E-06		1.10E-02
Jones River	1.71	1.00E-06		5.38E-02
Town Brook	0.31	1.00E-06		9.78E-03
Eel River	0.51	1.00E-06		1.61E-02
Herring River	0.37	1.00E-06		1.17E-02
Beaver Brook Dam	0.18	1.00E-06		5.68E-03
		Subtotal =	2.67E-01	
			TOTAL =	9.54E+00
			% Merrimack =	81%

1. A value of 1ng/l was selected for PCB concentration in surface water. This value is considered by Atlas et al. (1986) to be a "reasonable upper limit" for PCBs in average river water.

Table 51. Loadings of phthalates via rivers.

River Loads phthalates	Annual flow rate (m3/sec)	Conc. Used In Loadings Estimate (1) (mg/l)		Lower Estimated Loadings (Kg/Yr)
Merrimack Drainage				
Merrimack River	243.84	1.00E-04		7.69E+02
		Subtotal =	7.69E+02	
North Shore Drainage				
Ipswich River	6.46	1.00E-04		2.04E+01
Essex River	0.45	1.00E-04		1.42E+00
Rowley River	0.48	1.00E-04		1.51E+00
Parker River	2.86	1.00E-04		9.02E+00
Annisquam River	0.11	1.00E-04		3.47E-01
Bass River	0.07	1.00E-04		2.21E-01
North River		1.00E-04		0.00E+00
Danvers River	0.59	1.00E-04		1.86E+00
Crane River	0.28	1.00E-04		8.83E-01
Pines River	0.48	1.00E-04		1.51E+00
Saugus River	2.32	1.00E-04		7.32E+00
		Subtotal =	4.45E+01	
Boston Harbor Drainage				
Mystic River	3.18	1.00E-04		1.00E+01
Chelsea River		1.00E-04		0.00E+00
Charles River	15.35	1.00E-04		4.84E+01
Neponset River	5.58	1.00E-04		1.76E+01
Weymouth Fore River	6.28	1.00E-04		1.98E+01
Weymouth Back River	4.38	1.00E-04		1.38E+01
Weir River	1.25	1.00E-04		3.94E+00
		Subtotal =	1.14E+02	
South Shore Drainage				
South River	1.15	1.00E-04		3.63E+00
North River	3.90	1.00E-04		1.23E+01
Green Harbor River	0.35	1.00E-04		1.10E+00
Jones River	1.71	1.00E-04		5.38E+00
Town Brook	0.31	1.00E-04		9.78E-01
Eel River	0.51	1.00E-04		1.61E+00
Herring River	0.37	1.00E-04		1.17E+00
Beaver Brook Dam	0.18	1.00E-04		5.68E-01
		Subtotal =	2.67E+01	
			TOTAL =	9.54E+02
			% Merrimack =	81%

Table 52. Loadings of arsenic via rivers.

River Loads arsenic	Annual flow rate (m3/sec)	Years of Data	Avg Conc (mg/l)	Conc. Used in Loadings Estimate (mg/l)		Estimated Loadings (Kg/Yr)
Merrimack Drainage						
Merrimack River	243.84			1.00E-02		7.69E+04
				Subtotal =	7.69E+04	
North Shore Drainage						
Ipswich River	6.46			1.00E-02		2.04E+03
Essex River	0.45			1.00E-02		1.42E+02
Rowley River	0.48			1.00E-02		1.51E+02
Parker River	2.86	1	1.00E-03	1.00E-03		9.02E+01
Annisquam River	0.11			1.00E-02		3.47E+01
Bass River	0.07			1.00E-02		2.21E+01
North River				1.00E-02		0.00E+00
Danvers River	0.59			1.00E-02		1.86E+02
Crane River	0.28			1.00E-02		8.83E+01
Pines River	0.48			1.00E-02		1.51E+02
Saugus River	2.32			1.00E-02		7.32E+02
				Subtotal =	3.63E+03	
Boston Harbor Drainage						
Mystic River	3.18		5.00E-03	5.00E-03		5.01E+02
Chelsea River			6.30E-02	6.30E-02		0.00E+00
Charles River	15.35		5.40E-02	5.40E-02		2.61E+04
Neponset River	5.58		1.18E-01	1.18E-01		2.08E+04
Weymouth Fore River	6.28			1.00E-02		1.98E+03
Weymouth Back River	4.38			1.00E-02		1.38E+03
Weir River	1.25			1.00E-02		3.94E+02
				Subtotal =	5.12E+04	
South Shore Drainage						
South River	1.15			1.00E-02		3.63E+02
North River	3.90			1.00E-02		1.23E+03
Green Harbor River	0.35			1.00E-02		1.10E+02
Jones River	1.71			1.00E-02		5.38E+02
Town Brook	0.31			1.00E-02		9.78E+01
Eel River	0.51			1.00E-02		1.61E+02
Herring River	0.37			1.00E-02		1.17E+02
Beaver Brook Dam	0.18			1.00E-02		5.68E+01
				Subtotal =	2.67E+03	
		Maximum =	1.18E-01		**TOTAL =**	1.34E+05
		Minimum =	1.00E-03			
		Average =	4.82E-02		% Merrimack =	57%

1. A value of 0.01 mg/l is used for rivers for which we have no measurements. This value is selected as representative of typical maximum values in the United States rivers.

Table 53. Loadings of cadmium via rivers.

River Loads cadmium	Annual flow rate (m3/sec)	Cd Conc =	Estimated Loadings (Kg/Yr) 0.001 mg/l
Merrimack Drainage			
------------------------------------	243.84		7.69E+03
Merrimack River		Subtotals =	7.69E+03
North Shore Drainage			
------------------------------------	6.46		2.04E+02
Ipswich River	0.45		1.42E+01
Essex River	0.48		1.51E+01
Rowley River	2.86		9.02E+01
Parker River	0.11		3.47E+00
Annisquam River	0.07		2.21E+00
Bass River			0.00E+00
North River	0.59		1.86E+01
Danvers River	0.28		8.83E+00
Crane River	0.48		1.51E+01
Pines River	2.32		7.32E+01
Saugus River		Subtotals =	4.45E+02
Boston Harbor Drainage	3.18		1.00E+02
------------------------------------			0.00E+00
Mystic River	15.35		4.84E+02
Chelsea River	5.58		1.76E+02
Charles River	6.28		1.98E+02
Neponset River	4.38		1.38E+02
Weymouth Fore River	1.25		3.94E+01
Weymouth Back River		Subtotals =	1.14E+03
Weir River			
South Shore Drainage	1.15		3.63E+01
------------------------------------	3.90		1.23E+02
South River	0.35		1.10E+01
North River	1.71		5.38E+01
Green Harbor River	0.31		9.78E+00
Jones River	0.51		1.61E+01
Town Brook	0.37		1.17E+01
Eel River	0.18		5.68E+00
Herring River		Subtotals =	2.67E+02
Beaver Brook Dam			
		TOTAL =	9.54E+03
		% Merrimack =	81%

Table 54. Loadings of chromium via rivers.

River Loads chromium	Annual flow rate (m3/sec)	Cr Conc =	Estimated Loadings (Kg/Yr) 0.006 mg/l
Merrimack Drainage			
Merrimack River	243.84		4.61E+04
		Subtotals =	4.61E+04
North Shore Drainage			
Ipswich River	6.46		1.22E+03
Essex River	0.45		8.51E+01
Rowley River	0.48		9.08E+01
Parker River	2.86		5.41E+02
Annisquam River	0.11		2.08E+01
Bass River	0.07		1.32E+01
North River			0.00E+00
Danvers River	0.59		1.12E+02
Crane River	0.28		5.30E+01
Pines River	0.48		9.08E+01
Saugus River	2.32		4.39E+02
		Subtotals =	2.67E+03
Boston Harbor Drainage			
Mystic River	3.18		6.02E+02
Chelsea River			0.00E+00
Charles River	15.35		2.90E+03
Neponset River	5.58		1.06E+03
Weymouth Fore River	6.28		1.19E+03
Weymouth Back River	4.38		8.29E+02
Weir River	1.25		2.37E+02
		Subtotals =	6.82E+03
South Shore Drainage			
South River	1.15		2.18E+02
North River	3.90		7.38E+02
Green Harbor River	0.35		6.62E+01
Jones River	1.71		3.23E+02
Town Brook	0.31		5.87E+01
Eel River	0.51		9.65E+01
Herring River	0.37		7.00E+01
Beaver Brook Dam	0.18		3.41E+01
		Subtotals =	1.60E+03
		TOTAL =	5.72E+04
		% Merrimack =	**81%**

Table 55. Loadings of copper via rivers.

River Loads copper	Annual flow rate (m3/sec)	Cu Conc =	Estimated Loadings (Kg/Yr) 0.01 mg/l
Merrimack Drainage			
Merrimack River	243.84		7.69E+04
		Subtotals =	7.69E+04
North Shore Drainage			
Ipswich River	6.46		2.04E+03
Essex River	0.45		1.42E+02
Rowley River	0.48		1.51E+02
Parker River	2.86		9.02E+02
Annisquam River	0.11		3.47E+01
Bass River	0.07		2.21E+01
North River			0.00E+00
Danvers River	0.59		1.86E+02
Crane River	0.28		8.83E+01
Pines River	0.48		1.51E+02
Saugus River	2.32		7.32E+02
		Subtotals =	4.45E+03
Boston Harbor Drainage			
Mystic River	3.18		1.00E+03
Chelsea River			0.00E+00
Charles River	15.35		4.84E+03
Neponset River	5.58		1.76E+03
Weymouth Fore River	6.28		1.98E+03
Weymouth Back River	4.38		1.38E+03
Weir River	1.25		3.94E+02
		Subtotals =	1.14E+04
South Shore Drainage			
South River	1.15		3.63E+02
North River	3.90		1.23E+03
Green Harbor River	0.35		1.10E+02
Jones River	1.71		5.38E+02
Town Brook	0.31		9.78E+01
Eel River	0.51		1.61E+02
Herring River	0.37		1.17E+02
Beaver Brook Dam	0.18		5.68E+01
		Subtotals =	2.67E+03
		TOTAL =	9.54E+04
		% Merrimack =	**81%**

Table 56. Loadings of lead via rivers.

River Loads lead	Annual flow rate (m3/sec)	Pb Conc =	Estimated Loadings (Kg/Yr) 0.001 mg/l	Estimated Loadings (Kg/Yr) 0.03 mg/l
Merrimack Drainage				
Merrimack River	243.84		7.69E+03	2.31E+05
		Subtotals =	7.69E+03	2.31E+05
North Shore Drainage				
Ipswich River	6.46		2.04E+02	6.11E+03
Essex River	0.45		1.42E+01	4.26E+02
Rowley River	0.48		1.51E+01	4.54E+02
Parker River	2.86		9.02E+01	2.71E+03
Annisquam River	0.11		3.47E+00	1.04E+02
Bass River	0.07		2.21E+00	6.62E+01
North River			0.00E+00	0.00E+00
Danvers River	0.59		1.86E+01	5.58E+02
Crane River	0.28		8.83E+00	2.65E+02
Pines River	0.48		1.51E+01	4.54E+02
Saugus River	2.32		7.32E+01	2.19E+03
		Subtotals =	4.45E+02	1.33E+04
Boston Harbor Drainage				
Mystic River	3.18		1.00E+02	3.01E+03
Chelsea River			0.00E+00	0.00E+00
Charles River	15.35		4.84E+02	1.45E+04
Neponset River	5.58		1.76E+02	5.28E+03
Weymouth Fore River	6.28		1.98E+02	5.94E+03
Weymouth Back River	4.38		1.38E+02	4.14E+03
Weir River	1.25		3.94E+01	1.18E+03
		Subtotals =	1.14E+03	3.41E+04
South Shore Drainage				
South River	1.15		3.63E+01	1.09E+03
North River	3.90		1.23E+02	3.69E+03
Green Harbor River	0.35		1.10E+01	3.31E+02
Jones River	1.71		5.38E+01	1.62E+03
Town Brook	0.31		9.78E+00	2.93E+02
Eel River	0.51		1.61E+01	4.83E+02
Herring River	0.37		1.17E+01	3.50E+02
Beaver Brook Dam	0.18		5.68E+00	1.70E+02
		Subtotals =	2.67E+02	8.02E+03
		TOTAL =	9.54E+03	2.86E+05
		% Merrimack =	81%	81%

Table 57. Loadings of zinc via rivers.

River Loads zinc	Annual flow rate (m3/sec)	Zn Conc =	Estimated Loadings (Kg/Yr) 0.001 mg/l	Estimated Loadings (Kg/Yr) 0.03 mg/l
Merrimack Drainage				
Merrimack River	243.84		7.69E+03	2.31E+05
		Subtotals =	7.69E+03	2.31E+05
North Shore Drainage				
Ipswich River	6.46		2.04E+02	6.11E+03
Essex River	0.45		1.42E+01	4.26E+02
Rowley River	0.48		1.51E+01	4.54E+02
Parker River	2.86		9.02E+01	2.71E+03
Annisquam River	0.11		3.47E+00	1.04E+02
Bass River	0.07		2.21E+00	6.62E+01
North River			0.00E+00	0.00E+00
Danvers River	0.59		1.86E+01	5.58E+02
Crane River	0.28		8.83E+00	2.65E+02
Pines River	0.48		1.51E+01	4.54E+02
Saugus River	2.32		7.32E+01	2.19E+03
		Subtotals =	4.45E+02	1.33E+04
Boston Harbor Drainage				
Mystic River	3.18		1.00E+02	3.01E+03
Chelsea River			0.00E+00	0.00E+00
Charles River	15.35		4.84E+02	1.45E+04
Neponset River	5.58		1.76E+02	5.28E+03
Weymouth Fore River	6.28		1.98E+02	5.94E+03
Weymouth Back River	4.38		1.38E+02	4.14E+03
Weir River	1.25		3.94E+01	1.18E+03
		Subtotals =	1.14E+03	3.41E+04
South Shore Drainage				
South River	1.15		3.63E+01	1.09E+03
North River	3.90		1.23E+02	3.69E+03
Green Harbor River	0.35		1.10E+01	3.31E+02
Jones River	1.71		5.38E+01	1.62E+03
Town Brook	0.31		9.78E+00	2.93E+02
Eel River	0.51		1.61E+01	4.83E+02
Herring River	0.37		1.17E+01	3.50E+02
Beaver Brook Dam	0.18		5.68E+00	1.70E+02
		Subtotals =	2.67E+02	8.02E+03
		TOTAL =	9.54E+03	2.86E+05
		% Merrimack =	**81%**	**81%**

5.4 Loadings in Groundwater

Loads in groundwater were made only for selected watersheds and contaminants for which data were available.

5.4.1 Methods

Nitrogen Loading to Cape Cod Bay

We used two methods to estimate nitrogen loading into Cape Cod Bay and the watershed. The first method estimated nitrogen loadings into both Cape Cod Bay and its watershed (i.e., inputs to both the water and onto the land) by identifying significant inputs of nitrogen. The second method considered nitrogen loading just into Cape Cod Bay, including flow from groundwater. This second method required an estimate of both groundwater flow and nitrogen groundwater concentration. Note that here the term "Cape Cod Bay watershed" refers specifically to that area whose *groundwater* discharges into Cape Cod Bay.

We assumed that all groundwater in the Cape Cod Bay watershed discharges directly into Cape Cod Bay, thereby ignoring streams, springs, or other surface water. We also assumed steady-state conditions for the flow, concentration, and loading data. In addition, we assumed a contiguous groundwater divide exists, such that groundwater discharges on one side into Cape Cod Bay, on the other, into Buzzards Bay, Vineyard Sound, Nantucket Sound, and the Atlantic Ocean.

To estimate the location of the groundwater divide, we used a method similar to M. Frimpter (personal communication, M. Frimpter. We assumed that regionally the water table coincides with piezometric head. Orthogonal lines to groundwater contours therefore represent the migration of groundwater from a higher to lower fluid potential (i.e., the general directions of groundwater flow.) By determining the general directions of flow, the groundwater divide can be found.

We used the USGS groundwater atlas for Cape Cod (USGS Atlas HA-692, 1986) to obtain our groundwater profile. The atlas displays six discrete cells in which the water-table altitude is generally higher near the center of the cells, and lower near the coast. Thus groundwater generally flows from the center of the Cape to the coastlines. After approximating the groundwater divide for each cell, we connected them to create a contiguous divide for the Cape Cod region. Much of this groundwater divide coincides with Route 6, which in turn tends to coincide with topographic highs.

Only land lying within the Cape Cod Bay watershed was included in the analysis. For each town, this area was measured by digitizing the groundwater divide and town boundaries into ARC/INFO computer mapping system. Towns which have land lying within the watershed include Barnstable, Yarmouth, Sandwich, Dennis, Brewster, Orleans, Eastham, Provincetown, Wellfleet, and Truro. Note that Bourne was not included in the analysis, since we assessed that almost all of its nitrogen sources discharge into Buzzards Bay.

Estimates of Nitrogen Loading Using Method A: Discrete Loadings to Cape Cod Watershed

The first method identifies discrete sources of nitrogen introduced into the watershed. For each source, we calculated a respective nitrogen loading; we then summed these to obtain the total nitrogen loading. Sources of nitrogen considered are precipitation; septic systems; and lawn, agricultural, and golf course fertilizers. We ignored package treatment plants as a potential source since only a few are located within the Cape Cod Bay watershed.

Precipitation
We calculated a nitrogen loading to the watershed via precipitation by estimating an annual volume of precipitation and its associated nitrogen concentration. We calculated a mean precipitation rate of 1.1 m/year, based upon 1947 to 1976 data (USGS Atlas HA 692, 1986) for stations located within the Cape Cod Bay watershed. The annual volume of precipitation was found by multiplying the annual precipitation rate by the area of the watershed. We used a mean concentration of dissolved inorganic nitrogen (DIN) in precipitation of 22.4 uM, measured in Buttermilk Bay, an embayment of Cape Cod, by Valiela, et al., 1988. The nitrogen loading due to precipitation was calculated by multiplying the annual precipitation volume by the mean DIN concentration.

Domestic Fertilizer
To obtain a lawn fertilizer loading for the watershed, we first obtained the number of combined housing units for each town of concern (personal communications, towns' assessors). We define one combined housing unit as any residential building, regardless of the number of families residing there. Therefore, a four family home equals only one combined housing unit. Using approximations made by USGS (Frimpter, et al., July 1988), we assumed each housing unit possessed a lawn area of 5000 square feet.

In addition, we assumed that the percentage of both a town's land and its residential units within the watershed were identical. For example, if 30 percent of a town's land lies within the watershed, then 30 percent of its lawns do as well. Street maps of each town were used to assess the validity of this assumption. USGS (Frimpter, et al., July 1988) also provides a typical application rate of 2 lb/1000 square ft/year of nitrogen to the soil.

To calculate the nitrogen loading due to lawn fertilizer, we multiplied the mean lawn size by the number of lawns to obtain total lawn land use. We multiplied this area by the mean fertilizer application rate to obtain a mean total nitrogen loading.

Septic Systems
We calculated septic system loading for the Cape Cod Bay watershed based upon the number of residents per town. However, Barnstable County has disparate winter and summer populations. We therefore assumed nine months of a year only permanent residents would be present; the remaining three months of peak summer tourism, a substantially larger population was considered. We obtained each town's winter population through town clerks (personal communications, towns' clerks. In addition, some town clerks provided an estimate of their summer population. If no estimate on the summer population was available, winter population was tripled as a rough estimate (Persky, 1986). Similar to our assumption concerning housing

distributions, we assumed that the percentage of a town's area within the watershed would hold an identical percentage of the town's population.

We used a septic system infusion rate of 3.8 kg/DIN/person/year, based upon Valiela et al. (1988). We multiplied this rate by winter and summer populations within the watershed to obtain winter and summer loadings, respectively. Once weighted and summed (i.e. [9/12 winter population + 3/12 summer population]infusion rate), we obtained a total nitrogen loading due to septic systems.

Other Fertilizers
The most significant source of agricultural fertilizer on Cape Cod is cranberry production; we used 1980 cranberry bog land-use data for each town of concern from MacConnell, et al., 1984. Similar to our previous assumptions, we assumed that the percentage of a town's land within the watershed is identical to the percentage of the town's cranberry bog land use within the watershed. In addition, Valiela et al. (1988) provide a typical cranberry fertilizer application rate of 22.5 kg DIN/ha/yr. We multiplied these data together to obtain a nitrogen loading estimate for the watershed.

Finally, the nitrogen loading due to golf course fertilizer was estimated. This method is identical to that mentioned previously for agricultural fertilizer: land use data by town (MacConnell, et al., 1984), the percent area within the watershed, and a typical golf course fertilizer application rate of 99 DIN/acre/yr were used to calculate a loading. The application rate was obtained by taking the mean of application rates on several Cape Cod golf course fairways and roughs (Cape Cod Planning and Economic Development Commission, 1989).

Total Estimates
These individual estimates, when summed together, yield the nitrogen loading for the Cape Cod Bay watershed. From these estimates we calculated a nitrogen loading into Cape Cod Bay itself via groundwater.

<u>Estimate of Loadings Using Method A: Discrete Loadings to Cape Cod Bay</u>

The modeling previously applied to the Cape Cod Bay watershed can also be applied to Cape Cod Bay alone. This is accomplished by: (1) predicting the amount of nitrogen in the watershed which leaches into the groundwater; (2) assuming all of the nitrogen introduced into groundwater will discharge into Cape Cod Bay; (3) assuming the annual recharge into the Cape Cod Bay watershed dictates the annual discharge into Cape Cod Bay.

Precipitation
After DIN enters the watershed via precipitation, a portion of this nitrogen leaches from the zone of aeration into the groundwater. Since the nitrogen is dissolved, the area's recharge determines the amount of nitrogen to reach the groundwater. Once an annual estimate of recharge is found, a method identical to that used for precipitation loading into the watershed is used.

Our recharge data (USGS Atlas HA 692, 1986), based upon the mean annual precipitations used in Section 5.1 were estimated by USGS using the Thornthwaite and Mather (1957) method. The annual volume of recharge was then found by multiplying the annual recharge by the area of the Cape Cod Bay watershed. Again, we used the mean concentration of DIN in precipitation (22.4 uM). We assumed that all recharge discharges to the ocean and neglected minor discharges into canals or streams (USGS Atlas HA-692, 1986). Thus the nitrogen loading into the Bay was calculated by multiplying the annual recharge volume by the mean DIN concentration.

Septic Systems
Since septic systems are typically located at least four feet below topsoil, we assumed that none of its nitrogen will be available to plants for uptake. In addition, as Valiela et al. (1988) point out, denitrification in porous sand or groundwater are probably not significant, since the low amounts of dissolved inorganic carbon present here disallow microbial activity. Instead, we assumed that all of the nitrogen leaches directly into the groundwater, where it is eventually discharged into Cape Cod Bay. Thus, Cape Cod Bay and its watershed have identical estimates for nitrogen loading due to septic systems.

Fertilizers
We assessed what portion of fertilizer (and therefore nitrogen) would leach into groundwater, as opposed to plant uptake or denitrification. USGS (Frimpter, et al., 1988) states that typically, for the Cape Cod region, 45 to 50 percent of lawn fertilizer leaches into the groundwater. (The leachable portion of fertilizer depends on many factors including application rate, type of vegetation, and soil characteristics.) Similar estimates have been made for golf course fertilizer leachability, while no estimates could be obtained as cranberry fertilizer leachability. For simplicity, we assumed that for all of the previously mentioned fertilizers, the leachable to total fertilizer ratio is 0.5.

<u>Estimate of Loadings to Cape Cod Bay Using Method B: Groundwater Measurements and Discharge Rates</u>

We assumed in the second approach that a typical nitrogen concentration in groundwater exists, along with a typical groundwater flow rate. Although both nitrogen concentrations and flow in groundwater can vary widely locally, they are probably adequate to quantify a regional estimate for Cape Cod Bay. This method simply multiplies a representative nitrogen concentration by a representative flow in groundwater to obtain a nitrogen loading due to groundwater for Cape Cod Bay.

A data base of nitrate levels from private wells in Cape Cod was obtained through the Barnstable County Health Department. Each data base record had to meet the following criteria: (1) sample measured on or after 1 January 1989; and (2) sample taken from an area within the Cape Cod Bay watershed. Once these records were selected from the data base, various statistics were calculated in an attempt to obtain a representative nitrate concentration. It should be noted that this data set may contain an inherent bias: older homes (whose owners suspected possible water quality problems) were probably sampled most frequently. In some cases, however, sampling was conducted for real estate transactions or general information purposes. No ammonia concentrations for groundwater were available from this data base. Other sources of summary nitrate and ammonia concentrations for Cape Cod include two USGS publications to be discussed in Section 5.4.2.

We assumed that an amount of groundwater equal to the annual recharge in the Cape Cod Bay watershed would discharge annually into Cape Cod Bay. We used this value as our representative flow into Cape Cod Bay. Thus we could calculate a second estimate of nitrogen loading into Cape Cod Bay by calculating the groundwater flow by its associated concentration.

Groundwater Discharges to Boston Harbor

Estimates of loadings associated with groundwater discharges were made for the harbor as a whole by making estimates of possible groundwater discharge and estimating the concentrations of substances in groundwater.

An estimate of groundwater discharge to the harbor was made indirectly from the application of the NURP methodology. It was assumed that the areas considered for the purpose of runoff calculations in Menzie-Cura (1991) for MWRA were the same areas that would provide recharge to the harbor. Areas further landward were presumed to discharge groundwater to the major tributaries (e.g., Charles, Mystic, Neponset Rivers) and not directly to the harbor.

The NURP methodology provided an estimate of the amount of rainfall that becomes runoff and enters the harbor. By difference, the remaining rainfall either is lost to the atmosphere via evapotranspiration or recharges the shallow groundwater aquifers underlying the land masses considered in our analysis. Based on discussions with the USGS at Boston and Arlington, Virginia, it appears that approximately 50% of the rainfall that does not runoff would become groundwater and would eventually discharge to Boston Harbor. This is the basis of our flow estimate.

The concentrations of substances in the groundwater were estimated based on a review of the literature and an examination of groundwater data for several sites around Boston.

The following groundwater concentrations were used for our estimates for Boston Harbor:

Nitrogen
A concentration range of 0.1 to 1.0 mg/l is used. The lower end of this range is considered representative of coastal areas and the higher end may provide an upper bound of average groundwater conditions. The Maximum Contaminant Level (MCL) for nitrate in groundwater is 10 mg/l. Levels at and exceeding the MCL can typically be found in the immediate vicinity of subsurface sewage disposal systems and in agricultural areas.

Phosphorous
Phosphorous occurs in low concentrations in groundwater. Jones and Lee (1977) report a range of 0.01 to 0.06 ug/l nationwide. This range was used to estimate loadings.

Metals
Metals in groundwater can exhibit wide ranges in values (i.e., over several orders of magnitude). In developing ranges for groundwater discharging to Boston Harbor, we examined the groundwater monitoring results for three study sites in the Boston area, considered other information on the general levels of metals in groundwater and considered the existing MCL values for metals. The ranges we provided are probably on the high side for average natural groundwater conditions but are intended to give some indication of the implications of discharging slightly contaminated groundwater to the harbor:

- Cadmium: A range of 2 to 20 ug/l was selected. Groundwater levels of 2 to 29 ug/l and 6 to 20 ug/l were reported for studies at the Monsanto site in Everett and the Quincy Shipyard, respectively. The MCL for cadmium in drinking water is 10 ug/l (proposed value is 5 ug/l).

- Chromium: A range of 10 to 100 ug/l was selected. Groundwater levels of 3 to 1,900 ug/l were reported for the Quincy Shipyard. Typical values for chromium appear to be at or less than 10 ug/l. The MCL for chromium is 50 ug/l (proposed level is 100 ug/l.

- Copper: A range of 10 to 100 ug/l was selected. Groundwater levels of 7 to 28 ug/l and 20 to 1,000 ug/l were reported for the Monsanto Plant in Everett and the Quincy Shipyard, respectively. The MCL for copper is 1,3000 ug/l.

- Lead: A range of 1 to 100 ug/l was selected. Groundwater levels of 1 to 200 ug/l were reported for the Quincy Shipyard. The MCL for lead in raw drinking water is 5 ug/l.

- Nickel: A range of 10 to 100 was selected. Groundwater levels of 25 to 120 ug/l, 110 to 230 ug/l, and 20 to 165 ug/l were reported for the Monsanto, Parcel 18, and Quincy Shipyard sites, respectively. The MCL for nickel is 100 ug/l.

- Zinc: A range of 10 to 100 ug/l was selected. Groundwater levels of 17 to 230 ug/l, 6 to 11 ug/l, and 12 to 30,500 ug/l were reported for the Monsanto, Parcel 18,and Quincy Shipyard sites.

Polycyclic Aromatic Hydrocarbons (PAHs)
A range of 1 to 10 ng/l was selected based on the literature review carried out by Menzie et al. (1991). The proposed MCL for the PAH compound Benzo(a)pyrene is 200 ng/l.

Volatile Organic Compounds
Volatile organic compounds such as benzene, toluene, and xylene are mobile in groundwater and also are the substances that are most likely to be transported away from locations of petroleum spills or leaks of underground storage tanks. Based on our knowledge of the levels that occur in contaminated groundwaters (10s to 1,000s of ug/l), we have selected a range of 1 to 10 ug/l to represent average conditions for groundwater entering Boston Harbor.

5.4.2 Results: Nitrogen Loadings to Cape Cod Bay via Groundwater

Groundwater Divide
The estimated location of the groundwater divide for Cape Cod is presented in Figure 9. Areas to the north (and west for the arm of the Cape) of the divide are assumed to discharge groundwater into Cape Cod Bay. Using ARC/INFO to calculate areas with respect to the groundwater divide, we estimated that 25 percent of Barnstable County discharges into Cape Cod Bay. This estimate is broken down by town in Table 58.

Watershed Estimate
The resulting estimates of nitrogen loading into the watershed are presented in Table 58. We estimated the total nitrogen loading to the Cape Cod Bay watershed to be 447 metric tons/year. Just under half of this estimate is predicted to originate from septic systems, while lawn fertilizer and precipitation account for most of the remaining inputs. Golf course and agricultural fertilizers together accounted for only six percent of the total nitrogen inputs. Table 58 summarizes each input's loading, as well as its percent contribution to total inputs.

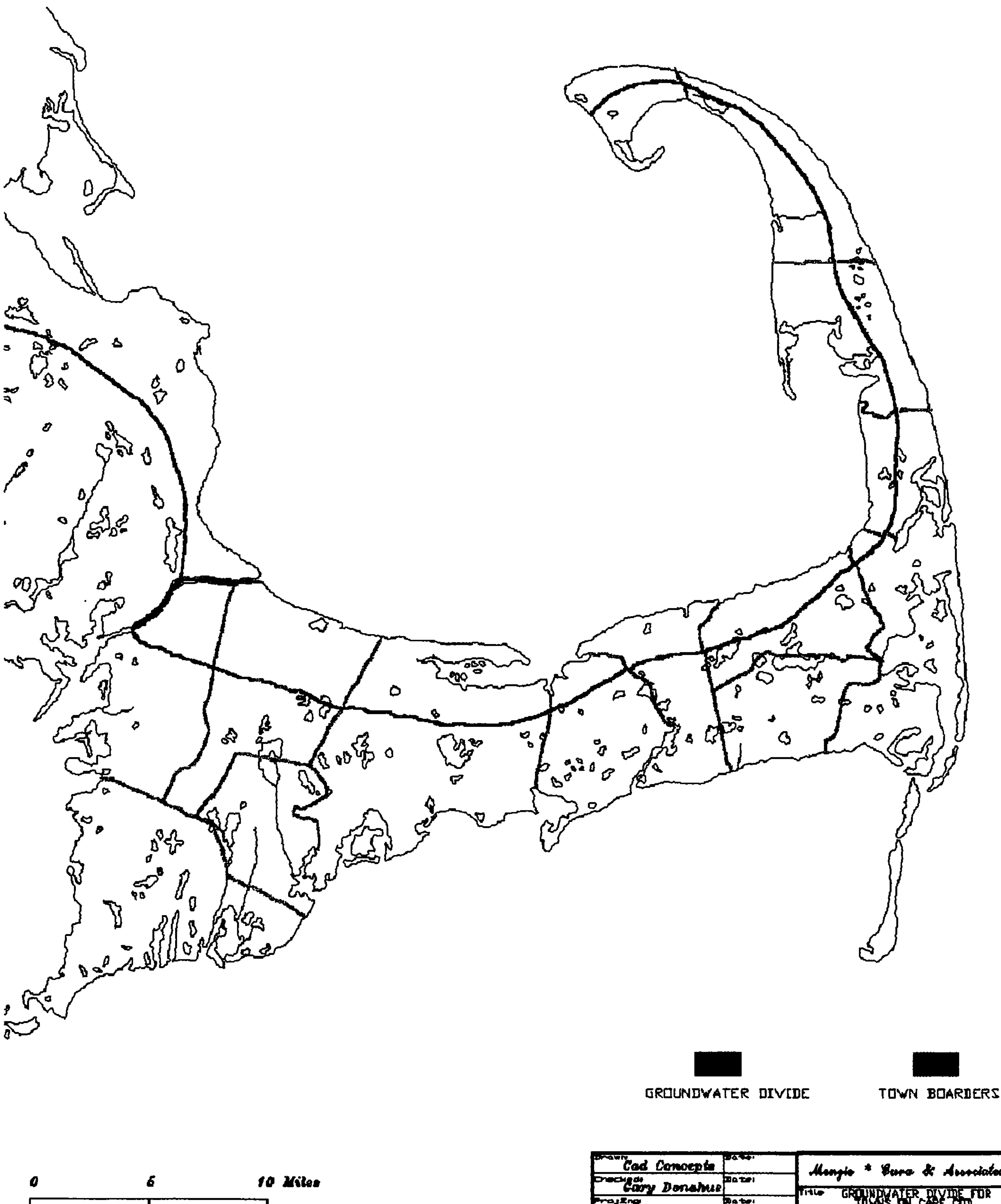


FIGURE 9

Drawn: Cad Concepts	Date:	Mangio * Gura & Associates, Inc.	
Checked: Gary Donahue	Date:	Title: GROUNDWATER DIVIDE FOR TOWNS ON CAPE COD	
ProjEng:	Date:	Size Document Number 0000	X
Appd:	Date:	Date: February 7, 1991 Sheet of	

Table 58. Recharge areas by town for Cape Cod.

Source	Year Measured	Nitrate (ug/l)	Statistic	Ammonia (ug/l)	Statistic
Frimpter, et al.	1979	0.12	median	0.01	median
Persky(1)	1980 -1984	1.54	weighted average	0.24	weighted average
Barnstable County Health Department	1989 - 1990	1.51	average	NA	
"	1989 - 1990	0.6	median	NA	
"	1989 - 1990	0.9	geometric mean	NA	

NA = Not Available

1. These values were calculated from histograms of nitrate and ammonia measured throughout Cape Cod.

Table 59. Nitrogen loadings from Cape Cod Bay watershed using discrete methods approach.

	Discrete Inputs Method				Groundwater Measurement Method	
	Cape Cod Bay Watershed		Cape Cod Bay		Cape Cod Bay	
	kg DIN/year	% of Total	kg DIN/year	% of Total	kg DIN/year	% of Total
Septic Systems	206,377	46%	206,377	64%		
Domestic Fertilizers	125,389	28%	62,694	20%		
Precipitation	90,280	20%	40,216	12%		
Other Fertilizers	25,063	6%	12,532	4%		
Totals	447,110	100%	321,819	100%	224,419	100%

The largest nitrogen input, septic systems, resulted in a loading of 206 metric tons DIN/year, which accounts for 46 percent of the total loading into the watershed. Valiela et al. (1988) estimated that 43 percent of the total loading into Buttermilk Bay watershed was due to septic systems. Cape Cod has undergone major housing developments in the past 15 years, thus drastically increasing the septage produced. Since, as Persky (1986) points out, Barnstable County's population is expected to continue its rapid increase, septic systems should continue to contribute a majority of the input into the watershed well into the next century.

Domestic fertilizers account for the next most significant input of nitrogen into the watershed. We calculated a DIN loading of 125 metric tons/year, accounting for 28 percent of our total loading, while Valiela et al. (1988) estimated lawn fertilizers contribute to 17 percent to Buttermilk Bay watershed. Precipitation accounted for 20 percent of our total, as compared to 34 percent for Buttermilk Bay. Golf course fertilizer accounted for only 22 metric tons DIN/year; agricultural fertilizer, 4 metric tons.

Cape Cod Bay Estimates
Groundwater is probably the most significant mechanism of transport of nitrogen into Cape Cod Bay. Valiela et al. estimate that 85 to 95 percent of all nitrogen input into Buttermilk Bay originates from groundwater transport. We have two results in which we estimated nitrogen transport via groundwater: our discrete inputs approach yielded 322 metric tons DIN/year while groundwater measurements predicted a slightly lower result of 224 metric tons DIN/year. By comparing the watershed loading to both the discrete inputs and groundwater measurement methods, we estimate between 50 and 72 percent of the nitrogen in the watershed discharges into the Bay.

Discrete Input Results
We estimate that 64 percent of nitrogen in groundwater is due to septic system loading; this results not only because septic systems were the largest input into the watershed, but also because nitrogen from septage does not typically experience denitrification or uptake from plants. Lawn fertilizer contributes 20 percent of the loading into the Bay while precipitation and golf and agricultural fertilizers make up the remaining 16 percent of inputs into the Bay. Table 60 summarizes each loading to Cape Cod Bay.

Groundwater Measurement Results
Table 60 provides a summary of representative measurements of nitrate and ammonia in groundwater on Cape Cod. The nitrate records selected from the Barnstable County Health Department private well data base (498 samples) were found to have neither a normal nor a lognormal distribution. This suggests that the median nitrate level would be more appropriate to represent the data set than the mean or geometric mean. The median nitrate concentration, 0.6 ug/l, is less than half of the mean, 1.51 ug/l. The Barnstable County nitrate data were used since they contained only recent measurements (1989 to 1990), selected only for the Cape Cod Bay watershed. Other sources include Frimpter, et al., (data from 1979) and Persky (data from 1980 to 1984).

Table 60. Loadings of nitrogen to Cape Cod Bay using discrete and groundwater measurements approach.

Nitrogen Loading via Precipitation		
Mean Recharge	0.49	m/year
Recharge Concentration	22.4	uM DIN
Town Area within Watershed	101.00	sq. miles
Volume of Recharge	1.28E+11	liter/year
Precipitation Loading	40,216	kg DIN/year
Nitrogen Loading via Septic Systems		
Septic System Infusion Rate	3.8	kg DIN/person/yr
Winter Population within Watershed	35,643	# of persons
Winter Septic System Loading	101,583	kg DIN/season
Summer Population within Watershed	110,310	Estimates
Summer Septic System Loading	104,795	kg DIN/season
Septic System Total Loading	206,377	kg DIN/year
Nitrogen Loading via Domestic Fertilizer		
Mean Lawn Area/Unit	5,000	sq ft
Mean Nitrogen Application Rate	2	lb/1000 sq ft/yr
Combined Residential Units within Watershed	27,643	residential unit
Leachable/Total Nitrogen Ratio	0.5	
Lawn Fertilizer Total Loading	62,694	kg DIN/year
Nitrogen Loading via Agricultural Fertilizer		
Cranberry Fertilizer Application Rate	22.5	kg DIN/ha/yr
Cranberry Bog Land Use within Watershed	378	acres
Leachable/Total Nitrogen Ratio	0.5	
Cranberry Fertilizer Total Loading	1,723	kg DIN/year
Nitrogen Loading via Golf Course Fertilizer		
Application Rate	99	lb DIN/acre/yr
Golf Course Land Use within Watershed	481	acres
Leachable/Total Nitrogen Ratio	0.5	
Golf Course Fertilizer Total Loading	10,809	kg DIN/year
Cape Cod Bay Watershed Nitrogen Loading:	321,819	kg DIN/year

Percent Contribution to Total Loading	
Septic Systems	64%
Domestic Fertilizers	19%
Precipitation	12%
Other Fertilizers	4%

Table 61. Summary of nitrate and ammonia concentrations used in the groundwater measurements approach.

	Watershed Totals		Barnstable	Yarmouth	Sandwich	Dennis	Brewster	Orleans	Eastham	Provincetown	Wellfleet	Truro
			Breakdown by Towns									
% Area of Town within Cape Cod Bay Watershed			33	14	53	35	33	9	48	52	61	56
Precipitation Nitrogen Loading												
Mean Precipitation	1.1	m/year										
Precipitation Concentration	22.4	uM DIN										
Town Area within watershed	101.00	sq. miles	20.70	3.57	23.12	7.67	8.30	1.28	7.01	4.55	12.70	12.10
Volume of Recharge	2.88E+11	liter/year										
Precipitation Loading	90,280	kg DIN/year										
Septic System Nitrogen Loading												
Septic System Infusion Rate	3.8	kg DIN/person/yr										
Winter Population within Watershed	35,643	# of persons	10,026	2,651	8,544	4,550	2,599	545	2,230	1,921	1,647	930
Winter Septic System Loading	101,583	kg DIN/season	28,574	7,554	24,349	12,968	7,407	1,555	6,354	5,476	4,694	2,651
Summer Population within Watershed	110,310	Estimates	29,700	7,000	25,440	13,650	7,920	1,620	7,200	8,320	6,100	3,360
Summer Septic System Loading	104,795	kg DIN/season	28,215	6,650	24,168	12,968	7,524	1,539	6,840	7,904	5,795	3,192
Septic System Total Loading	206,377	kg DIN/year	56,789	14,204	48,517	25,935	14,931	3,094	13,194	13,380	10,489	5,843
Lawn Fertilizer Nitrogen Loading												
Mean Lawn Area/Unit	5,000	sq ft										
Mean Nitrogen Application Rate	2	lb/1000 sq ft/yr										
Combined Residential Units within Watershed	27,643	residential unit	6,699	1,653	6,890	4,498	1,419	398	2,360	1,292	1,545	892
Lawn Fertilizer Total Loading	125,389	kg DIN/year	30,388	7,499	31,253	20,402	6,437	1,796	10,703	5,861	7,008	4,044
Cranberry Bog Fertilizer Nitrogen Loading												
Cranberry Fertilizer Application Rate	22.5	kg DIN/ha/yr										
Cranberry Bog Land Use within Watershed	378	acres	149	46	90	22	68	1	0	0	2	0
Cranberry Fertilizer Total Loading	3,445	kg DIN/year	1,353	422	821	201	616	9	0	0	22	0
Golf Course Fertilizer Nitrogen Loading												
Application Rate	99	lb DIN/acre/yr										
Golf Course Land Use within Watershed	481	acres	185	19	155	35	36	0	0	0	33	18
Golf Course Fertilizer Total Loading	21,618	kg DIN/year	8,299	874	6,950	1,572	1,615	0	0	0	1,479	830
Total Cape Cod Bay Watershed DIN Loading:	447,110	kg DIN/year										

Percent Contribution to Total Loading	
Septic Systems	46%
Domestic Fertilizers	28%
Precipitation	20%
Other Fertilizers	6%

Persky presented histograms of nitrate and ammonia concentrations (number of samples for each class and range of each class), from which mean concentrations were calculated. The nitrate and ammonia data reported by Frimpter, et al. is significantly less than those calculated from Persky (0.12 vs. 1.54 ug/l nitrate and 0.01 vs. 0.24 ug/l ammonia). Presumably, this difference over a few years is due to rapid population increases and a housing boom. Since ammonia concentrations were not available from the Barnstable County data base, the ammonia concentration calculated from the Persky report was used. Since this was an average ammonia concentration, we used the *average* nitrate concentration of 1.51 ug/l from the Barnstable Health data base in lieu of the median. This choice permitted us to sum the two values to obtain an average nitrogen concentration. Using the average concentration is probably an overestimate due to the non-normality of the nitrate data base.

The representative flow of groundwater in the watershed was estimated using the annual recharge. We assumed that whatever recharge enters the watersheds' aquifers, an equal amount of groundwater would be discharged. Thus, a flow rate of 1.28E+11 liters groundwater/year was assumed to discharge into Cape Cod Bay. We then obtain a nitrogen loading into Cape Cod Bay via groundwater of 224 metric tons/year.

5.4.3 Results: Groundwater Loadings to Boston Harbor

Groundwater flow to the North and South Harbors was estimated to be approximately 1 m^3/sec. The estimated loadings of substances associated with the discharge of groundwater are provided in Table 62.

Table 62. Estimates of loadings via groundwater to Boston Harbor.

Constituent	Low Estimate		High Estimate
Total Flow (m3/s)	------->	1 m3/s	
Conventionals (mt/yr)			
Total BOD		not determined	
Total Nitrogen	1.6		15.7
Total Phosphorus	1.6E-04		9.5E-04
Total Solids		not determined	
Total Coliforms		not determined	
Metals (kg/yr)			
Cadmium	32		320
Chromium	160		1600
Copper	160		1600
Lead	16		1600
Mercury		not determined	
Nickel	160		1600
Zinc	160		1600
Organic Compounds (kg/yr)			
PCBs		not determined	
PAHs	0.02		0.2
Phthalates		not determined	
Volatile Organic Cmpds	16		160

5.5 Loadings Associated with Dredged Material Disposal

5.5.1 General Approach

This section of the report provides estimates of pollutant loadings resulting from the ocean disposal of dredged material at the ocean disposal site in Massachusetts Bay (Figure 2). The continuous effort to dredge and maintain the waterways and shipping channels of Massachusetts Bay results in the creation of large amounts of dredged material for disposal. This material, because it comes from waterways located in urban and industrial areas, may be contaminated with various pollutants. Dredged material disposal is regulated by the U.S. Army Corps of Engineers (USACE) and EPA. Disposal takes place at two locations within the bay. The first of these is the Massachusetts Bay Disposal Site, located at the Northeastern edge of the Stellwagen Basin. The second site is located in Cape Cod Bay, and, is used only for the disposal of clean sandy materials from the dredging of the Cape Cod Canal.

Prior to disposal the USACE requires that sediments be analyzed for the following metals: mercury, cadmium, lead, chromium, copper, nickel, zinc and arsenic. In addition concentrations of PCBs, volatile organics and oils are measured. PAHs are not measured in materials destined for ocean disposal. However, data on levels of these compounds in coastal marine sediments can be used to provide an estimate of loadings.

Using data showing the volume of materials disposed of at the Massachusetts Bay Disposal Site from 1976 through 1987 and concentrations of contaminants in the sediments (Hubbard, Penko and Fleming, 1988), we have calculated the loadings of these materials to the bay.

5.5.2 Calculation of Loadings.

The USACE data are presented in terms of barge volumes of sediment in cubic meters per year. We multiplied these volumes by a factor of 0.65 to convert barge volume to in-place sediment volume as suggested by Tavalaro (1985).

Metals data are presented as weighted annual averages, in parts per million dry weight. The water content of sediment samples vary widely and is dependent on the grain-size and distribution. Based on discussions with Glenn Jones at Woods Hole Oceanographic Institution, we estimated that 1 cubic meter of wet sediment contains approximately 1 metric ton of sediment on a dry weight basis.

The following formula was used to calculate the loading of a particular metal:

$$\textbf{Metal (mt)} = \frac{\textbf{Sediment (mt) x Metal Concentration (mg/kg)}}{\textbf{1,000,000 (conversion factor)}}$$

The results of the calculations are presented in Table 63. There are several sources of uncertainty in the calculations. Based on conversations with Mr. Fredette of the USACE, we assumed that the material at the Cape Cod Bay disposal site is clean and therefore did not contribute to pollutant loadings. Thus, the estimates are for those materials that are dumped at the ocean disposal site in Massachusetts Bay alone. Weighted, averaged data are used in the estimates, and it must be recognized that there is variability among samples. For example the weighted average for mercury was 0.68 ppm, while the standard deviation was 0.9 ppm.

Some uncertainty is introduced when converting from wet weight to dry weight. We estimated that a cubic meter of wet in-place sediment would contain approximately one metric ton of dry solids. However, the range, depending on bulk density could fall between 0.6 to 1.2 metric tons of dry sediment per cubic meter of in-place wet sediment. In addition, the factor for conversion from barge estimates to in place sediment volumes will varies with the amount of water entrained in the sediments during the dredging process.

Table 63. Loadings to Massachusetts Bay due to dredged material disposal.

METALS >>>——————>

Dredged Materials Year	Barge Volume m3	In-Place Volume m3	Hg Metric Tons	Cd Metric Tons	Pb Metric Tons	Cr Metric Tons	Cu Metric Tons	Ni Metric Tons	Zn Metric Tons	As Metric Tons
1976	239,746.00	155,834.90	0.1060	0.46	19.77	16.50	16.30	5.73	26.62	1.97
1977	38,400.00	24,960.00	0.0170	0.07	3.17	2.64	2.61	0.92	4.26	0.32
1978	25,320.00	16,458.00	0.0112	0.05	2.09	1.74	1.72	0.60	2.81	0.21
1979	70,273.00	45,677.45	0.0311	0.14	5.79	4.84	4.78	1.68	7.80	0.58
1980	11,552.00	7,508.80	0.0051	0.02	0.95	0.80	0.79	0.28	1.28	0.09
1981	241,004.00	156,652.60	0.1065	0.46	19.87	16.59	16.39	5.76	26.76	1.98
1982	646,713.00	420,363.45	0.2858	1.24	53.32	44.51	43.97	15.45	71.81	5.31
1983	216,320.00	140,608.00	0.0956	0.42	17.83	14.89	14.71	5.17	24.02	1.78
1984	173,081.00	112,502.65	0.0765	0.33	14.27	11.91	11.77	4.14	19.22	1.42
1985	209,007.00	135,854.55	0.0924	0.40	17.23	14.38	14.21	4.99	23.21	1.72
1986	177,480.00	115,362.00	0.0784	0.34	14.63	12.21	12.07	4.24	19.71	1.46
1987	90,834.00	59,042.10	0.0401	0.17	7.49	6.25	6.18	2.17	10.09	0.75
Average Load	178,310.8333	115,902.0417	0.0788	0.34	14.70	12.27	12.12	4.26	19.80	1.46

ORGANICS

Dredged Materials Year	PAHs MT '@ 0.1 mg/kg	PAHs PAH '@ 10 mg/kg	PCB MT '@ 0.2 mg/kg	Oil Metric Tons
1976	0.0156	1.5583	0.0343	3319.28
1977	0.0025	0.2496	0.0055	531.65
1978	0.0016	0.1646	0.0036	350.56
1979	0.0046	0.4568	0.0100	972.93
1980	0.0008	0.0751	0.0017	159.94
1981	0.0157	1.5665	0.0345	3336.70
1982	0.0420	4.2036	0.0925	8953.74
1983	0.0141	1.4061	0.0309	2994.95
1984	0.0113	1.1250	0.0248	2396.31
1985	0.0136	1.3585	0.0299	2893.70
1986	0.0115	1.1536	0.0254	2457.21
1987	0.0059	0.5904	0.0130	1257.60
Average Load	0.0116	1.1590	0.0255	2468.71

5.6 Loadings Associated with Atmospheric Deposition

The atmospheric loading of selected nutrients, organic compounds and metals to the Massachusetts Bays is estimated in this section. The listed metals, except for iron, have been identified as toxic or potentially toxic by Wood (1974). Iron is included in the loading analysis because it is listed as a pollutant in the NCPDI (Farrow et al., 1986). Beryllium, although listed as toxic by Wood (1974), is not analyzed because of the lack of data pertaining to the Massachusetts Bays region. The limited data available on the aerosol concentration of beryllium (Measures et al., 1984) indicates that atmospheric loading to the western North Atlantic is not significant. Atmospheric deposition of beryllium to the Massachusetts Bays therefore is not likely to be significant. The atmospheric loading of the organic pollutants PAH and PCB are also estimated in this section as are the nutrients nitrogen and phosphorus.

Atmospheric loading was calculated as the sum of dry and wet depositional flux integrated over the entire area of the Massachusetts Bays. Dry deposition is the direct settling of aerosol-bound pollutants. Dry flux is calculated by multiplying the measured aerosol concentration by an estimated deposition velocity. Wet deposition results from the scavenging of aerosol- bound pollutants by rain and snow. Concentration in precipitation has been measured directly for some pollutants. Where such measurements were available, the concentration was multiplied by the precipitation rate per unit area to estimate wet depositional flux. Where wet concentration has not been measured directly, it was estimated by multiplying the dry concentration by a scavenging or "washout" ratio, i.e., the ratio of measured wet and dry concentrations, as reported in refereed literature. The combined dry flux and wet flux are multiplied by the surface area of the Massachusetts Bays to obtain the loading from atmospheric deposition.

Atmospheric concentration data were found in refereed literature that pertain specifically to the Massachusetts Bays region for all chemicals except mercury and phosphorus (Table 64). Loadings were estimated for these chemicals based on regional concentrations or concentrations represented as characteristic of urban areas. The data sources for each chemical are discussed in detail in subsections 5.3.1 through 5.3.3. Some of the most relevant data were provided by Ilhan Olmez of the Massachusetts Institute of Technology.

The estimate of atmospheric flux is assumed to apply equally to all the Massachusetts Bays, regardless of distance from the measurement location. The spatial sampling of aerosol concentration is generally inadequate to estimate concentration gradients, so a point estimate of flux is used to calculate loadings. This approach may introduce a bias towards higher loadings since many of the measurements have been made in urban areas and almost none have been made in the marine atmosphere. This potential bias is minimized by restricting the concentration data to submicron-sized

Table 64. Parameters used to estimate atmospheric loading.

Chemical	Deposition Velocity, Vd (cm/s)	Washout Ratio, W	Atmospheric Concentration (ng/m3)
Metals			
Sb	0.1	---	9.1
As	0.22	110	0.8
Cd	0.45	125	3
Cr	0.5	150	3.4
Co	0.3	---	1
Cu	0.5	140	16.1
Fe	1.1	250	75.7
Pb	0.3	76	326
Mn	0.56	370	3.6
Hg	---	---	---
Mo	---	---	0.14 to 2
Ni	0.7	gw 125	8.6
Se	0.1	---	0.6
Ag	0.24	---	0.5
V	0.29	110	25
Zn	0.62	179	38.7
Organic Compounds			
PAH	0.53		1.5 to 2
PCB	0.16	86	1.4 to 3.9
Nutrients			
t-N	0.4	---	1700 to 5500
t-P	---	---	---

particles which have a higher likelihood of dispersing over the entire study area than coarser particles. In order to represent the variability in the concentration measurements, the 10th and 90th percentiles of the frequency distribution are used as bounds on the range of concentration in the study area. These estimates are based on a log-normal distribution.

Loadings are estimated on an annual basis only. The seasonal variation of atmospheric concentration has not been measured for most of the pollutants in this study. Rainfall, affecting the amount of wet deposition, does not have a strong seasonal dependence as described further below.

Dry deposition flux is calculated by multiplying the atmospheric concentration, C, by a characteristic deposition velocity, Vd:

$$\mathbf{Fd = Vd \cdot C} \qquad (1)$$

which is the approach used by Hicks et al. (1988) and other investigators. Deposition velocities are reported for metals by McMahon (1979), Sehmel (1980), McVeety and Hites (1988), for organics by McVeety and Hites (1988), and for nutrients (nitrogen) by Galloway et al. (1987).

Wet deposition flux is calculated by multiplying the atmospheric concentration by the precipitation rate, P, and the volumetric washout ratio, Wv, for each specific chemical:

$$\mathbf{Fw = Wv \cdot P \cdot C} \qquad (2)$$

The volumetric washout ratio is defined as the ratio of concentration in precipitation to the concentration in unscavenged air:

$$\mathbf{Wv = \frac{(ug/l),rain}{(ng/m3),air}} \qquad (3)$$

Washout ratios for metals were reported by McMahon (1979) and by Jaffrezo and Colin (1988), and for organic compounds by Ligocki et al. (1985 a,b). Washout ratios are not available for antimony, mercury, molybdenum, selenium, silver, nitrogen or phosphorus. (Wet deposition flux of mercury, molybdenum, silver, nitrogen and phosphorus was determined directly from estimates of concentration in rainfall).

Precipitation in the Massachusetts Bays region was measured on Cape Cod and in a Boston suburb as part of the National Atmospheric Deposition Program (Table 65). Annual precipitation is about 1.1 m/yr. Precipitation rates show little seasonal variation. Wet concentration is presented in units of ug/l and wet deposition flux in units of mg/m2/yr.

Table 65. Seasonal and annual rainfall (cm) in the Massachusetts Bays region measured at two sites in the National Atmospheric Deposition Program.

	TOTAL	FALL	WINTER	SPRING	SUMMER
	North Atlantic Coastal Lab Barnstable County MA				
1982	134.12	35.01	28.60	27.38	42.70
1983	160.47	38.28	31.09	56.97	28.99
1984	134.52	24.38	34.53	44.39	36.68
1985	121.00	23.04	17.12	31.05	54.75
1986	118.93	27.38	21.63	21.36	34.18
1987	58.01	16.10	49.40	-----	-----
1988	96.36	36.18	30.02	17.67	17.38
	East Middlesex County MA				
1982	96.14	20.07	4.75	21.97	46.46
1983	133.65	35.99	24.39	47.32	14.47
1984	122.53	17.64	39.47	32.84	39.50
1985	92.13	30.94	13.26	20.15	33.15
1986	107.55	23.10	17.53	16.76	33.71
1987	102.81	30.83	37.16	31.37	16.27
1988	92.88	28.34	19.66	23.66	24.58

The flux determined from analysis of dry and wet deposition are multiplied by the area of each of the Massachusetts Bays (Table 66). These bays were identified and their areas were estimated at the MIT Collegium, 1989. The total area of the Massachusetts Bays closely matches that of Long Island Sound, 3,350 km2 (Connecticut Department of Environmental Protection, 1987), which is used for comparison of some of the loading estimates. Summaries by land use (i.e., urban, rural, marine) such as Galloway et al. (1982) for wet deposition and such as the Gas Research Institute for PAH data are also used for comparison purposes.

Table 66. Areas of Massachusetts Bays.

Location	Area km2
Massachusetts Bay	2200
Cape Cod Bay	1300
Broad Sound	66
North Harbor	41
Quincy Bay	38
Inner Harbor	10
Hingham Bay	19
Total	3700

Annual loadings of metals, organic pollutants and nutrients are presented in the following subsections.

5.6.1 Nutrients

Nitrogen

Atmospheric concentration of nitrogen is reported to be 1700 ng N/m^3 as measured 50 km east of Boston (Galloway et al., 1987), and 5500 ng N/m^3 for the northeastern U.S. (Galloway et al., 1984). These concentrations are used as the lower and upper range limits, respectively, for the present analysis.

Deposition velocity of nitrogen (as NOx) is reported to be 0.4 cm/s by Galloway et al. (1987); deposition velocity of NO3+HNO3 is 0.8 cm/s. The deposition velocity used for nitrogen in the present analysis is 0.4 cm/s. This deposition velocity results in a dry deposition flux of 214 to 694 mg/m2/yr.

No data are available on the washout ratio of nitrogen.

Wet deposition is calculated directly from measurements of nitrogen concentration in precipitation at stations on Cape Cod and in a suburb of Boston (NADP, 1989). These concentrations ranged from 200 to 479 ug/l, a combination of NO3 and NH4. These data exhibited seasonal variation, largest concentrations in summer, smallest in winter.

The estimate of atmospheric loading of nitrogen to the Massachusetts Bays is presented in Table 67. Total annual loading of nitrogen is estimated to be 1759 to 4944 tons/yr.

Table 67. Atmospheric loading (kg/yr) of nitrogen to Massachusetts Bays. Estimate includes wet and dry deposition.

Area	Low Estimate	High Estimate
Mass Bay	955779	2685522
Cape Cod Bay	564778	1586900
Broad Sound	28673	80566
North Harbor	17812	50048
Quincy Bay	16509	46386
Inner Harbor	4344	12207
Hingham Bay	8254	23193
Total	1596150	4484822

Phosphorus

Graham and Duce (1982) measured the concentration of phosphorus off Cape Cod to be 19 ng/m3 t-P. Deposition velocity was estimated to be 0.4(0.2) cm/s. The resulting dry deposition flux is then 1.2 mg/m2/yr.

Wet concentrations of 2 ug/l and 11.6 ug/l were measured by Graham and Duce (1982) in the western Atlantic near the study area. This results in a wet deposition flux of 12 to 70 mg/m2/yr for the study area. The wet deposition flux for Long Island Sound (Connecticut Department of Environmental Protection, 1987), as measured by USGS, is 11.1 mg/m2/yr, indicating that the lower estimates are probably more representative.

The estimate of atmospheric loading of phosphorus to the Massachusetts Bays is presented in Table 68. Total annual loading of phosphorus is estimated to be 14 to 290 tons/yr.

Table 68. Atmospheric loading (kg/yr) of phosphorus to Massachusetts Bays. Estimate includes dry and wet deposition.

Area	Low	High
Mass Bay	7476	30708
Cape Cod Bay	4418	18146
Broad Sound	224	921
North Harbor	139	572
Quincy Bay	129	530
Inner Harbor	34	140
Hingham Bay	65	265
Total	12486	51283

5.6.2 Organic Compounds

Atmospheric loadings of PAH and PCB to Massachusetts Bays are estimated in this subsection.

PAH loading to Massachusetts Bays is of concern because of the carcinogenic potential of some PAH compounds. Kertesz-Saringer et al. (1971), for instance, identify benzo[a]pyrene as a very dangerous carcinogen. The atmospheric concentration of B[a]P has been monitored by the EPA at stations in Boston and in Chelsea. Dry deposition flux is determined from these concentrations and an estimate of deposition velocity. Wet deposition flux is determined from these concentrations and an estimate of the washout ratio. Extrapolation to total PAH from the estimates for B[a]P is based on the relative abundances of PAH compounds measured in sediments in Boston Harbor. This approach to estimating t-PAH suffers from variabilities among the PAH compounds in particle size distribution, aerosol-vapor partitioning, and washout ratios for aerosol and vapor phases.

PCB loading to Massachusetts Bays is calculated on the basis of regional measurements of atmospheric concentration of PCB as Aroclor 1254. Deposition velocity and washout ratios for Aroclor 1254 are used to estimate dry and wet deposition fluxes and total atmospheric loading. This approach neglects other congeners, but loading of t-PCB is likely to be dominated by Aroclor 1254.

PAH

Atmospheric concentration of B[a]P is reported to be 0.2 ng/m3 (U.S. EPA AIRS, 1990). These concentrations are similar to those for the low range of urban areas by the Gas Research Institute (Atlantic Environmental Services, 1988).

No data are available on the atmospheric concentration of other PAH compounds in the Massachusetts Bays region. The relative abundance of PAH compounds measured in sediments from Boston Harbor and remote sites along the New England coast may reflect to some extent the composition in atmospheric deposition and is used here to derive total PAH inputs from data on B[a]P. A limitation on using these data as a basis for estimating total PAH inputs is that PAH compounds seem to be apportioned among different particle sizes based on their molecular weight. High molecular weight compounds, such as B[a]P, are associated with submicron-sized particles on which they were emitted while low molecular weight compounds, such as fluoranthene, can migrate to larger particles (DeWiest, 1978).)

Gshwend and Hites (1981) found that B[a]P comprised 10% of the total PAH in sediments from Boston Harbor and at a remote site off the coast of Maine; Shiaris and Jambord-Sweet (1986) reported B[a]P concentrations that average 13% of t-PAH (variability was large, 2 to 40%). Assuming that B[a]P comprised 10 to 13% of the total PAH in air, the concentration of t-PAH in air was 1.5 to 2 ng/m3. This estimate is similar to the mean urban concentration, 3 ng/m3, reported by the Gas Research Institute (Atlantic Environmental Services, 1988).

Deposition velocity of PAH is reported to be 0.53 cm/s for combined vapor and aerosol by McVeety and Hite (1988). This deposition velocity was used for PAH in the present analysis and results in a dry deposition flux of 0.25 to 0.33 mg/m2/yr. This estimate is similar to the total deposition flux, 0.2 mg/m2/yr, measured at a remote site by Gschwend and Hites (1981). Wet deposition was estimated from the concentration of t-PAH in air and the scavenging ratio. Ligocki et al. (1985 a,b) have measured the scavenging ratio for gas phase and particle phase PAH in coastal and urban Oregon. Particulate washout is important only for the higher molecular weight compounds, e.g., benzo[a]pyrene. Lower molecular weight compounds, e.g. phenanthrene, have predominantly gas phase washout. B[a]P and phenanthrene flux were determined to be about the same by Gschwend and Hites (1981), 0.17 and 0.24 mg/m2/yr. This result may indicate that B[a]P scavenging is representative of total PAH scavenging, even though most PAH compounds are scavenged through their gas phase. Based on the measured concentration of B[a]P, 0.2 ng/m3, and a particulate washout ratio of 1700, the concentration in rain is estimated as 0.34 ng/l. Extrapolating from B[a]P to t-PAH results in estimates of 2.6 to 3.4 ng t-PAH/l. This estimate is about the same as the estimate of wet deposition made by Gschwend & Hites (1981) based on concentration in rain at the Great Lakes by Eisenreich et al. (1981).

The estimate of atmospheric loading of total PAH to the Massachusetts Bays is presented in Table 69. Total annual loading of PAH is on the order of 1 metric ton/yr. Dry deposition dominates the loading, which may be expected because of the low efficiency of scavenging submicron-sized particles (Gschwend & Hites, 1981). It is approximately the same as the estimate of atmospheric loading made by Gschwend and Hites (1981), but is low by a factor of 2 to 10 compared with estimates presented at the MIT Collegium (1989).

Table 69. Atmospheric loading (kg/yr) of PAHs to Massachusetts Bays (dry and wet).

Area	Low Estimate	High Estimate
Mass Bay	571	755
Cape Cod Bay	337	446
Broad Sound	17	23
North Harbor	11	14
Quincy Bay	10	13
Inner Harbor	3	3
Hingham Bay	5	7
Total	953	1260

PCB

Atmospheric concentration of PCB (as Aroclor 1254) is reported to be 1.4 ng/m3 at Georges Bank and 3.9 ng/m3 at Vineyard Sound (Harvey and Steinhauer, 1974). These concentrations are used as the lower and upper range limits, respectively, for the present analysis.

Deposition velocity of PCB (Aroclor 1254) is reported to be 0.16 cm/s by McVeety and Hites (1988); deposition velocity of t- PCB is 0.13 cm/s and for PCB aerosol is 0.91 cm/s. The deposition velocity used for PCB in the present analysis is 0.16 cm/s. This deposition velocity results in a dry deposition flux of 0.07 to 9.20 mg/m2/yr.

The washout ratio for PCB is 86, according to Mackay et al. (1986). This results in a wet deposition flux of 0.12 to 0.34 mg/m2/yr.

The dry:wet ratio calculated in the present analysis (1:2) is in moderate agreement with the ratio for the Great Lakes (1:3) reported by Swackhamer et al. (1988).

The estimate of atmospheric loading of PCB to the Massachusetts Bays is presented in Table 70. Total annual loading of PCB is estimated to be 1 to 2 metric tons/yr.

Table 70. Atmospheric loading (kg/yr) of PCBs to Massachusetts Bays. Estimates include dry and wet deposition.

Area	Low Estimate	High Estimate
Mass Bay	446	1256
Cape Cod Bay	263	742
Broad Sound	13	38
North Harbor	8	23
Quincy Bay	8	22
Inner Harbor	2	6
Hingham Bay	4	11
Total	745	2097

5.6.3 Atmospheric loading of metals.

The principal data sources for atmospheric metal concentrations are Zoller and Gordon (1970), Gladney et al. (1974), Hopke et al. (1976), Fogg and Fitzgerald (1979), Rahn (1981), Rahn and Lowenthal (1984), Thurston and Spengler (1985), and Olmez (1990).

Zoller and Gordon (1970) analyzed samples collected at MIT and other locations in the Boston area. Instrumental neutron activation analysis provided results for a large suite of metals. Gladney et al. (1974) analyzed samples collected from two sites at MIT: the roof of the Nuclear Chemistry Building and the roof of the Green Building (100 m above ground level) and from one site west of Route 128 in Wellesley. Size distribution was also determined. Zoller and Gordon (1970) and Gladney et al. (1974) both used instrumental neutron activation analysis. Hopke et al. (1976) analyzed samples taken from locations around the perimeter of Boston Harbor (Hull, Long Island, Massachusetts General Hospital, Boston Naval Shipyard, Logan International Airport) and at Wellesley. They used INAA on 90 total samples.

Fogg and Fitzgerald (1979) measured the concentration of mercury in rainwater at a site on Cape Cod (Centerville, MA) during September and October, 1975.

Rahn (1981) measured the concentration of manganese and vanadium at a rural site in Narragansett, RI for the purpose of establishing regional tracers. Rahn and Lowenthal (1984) measured arsenic, antimony, selenium, vanadium, zinc, manganese, and indium at Narragansett. They isolated measurements obtained during winds from the Boston area in order to identify a Boston signature.

Data used for comparison purposes were found in Scudlark and Church (1988), Galloway et al. (1982), and Connecticut Department of Environmental Protection (1987). Scudlark and Church measured arsenic concentration at a remote site at Lewes, DE. Galloway et al. (1982) summarized reports of metal concentration in precipitation, categorized by urban, rural, and marine areas or by specific areas in some cases. Connecticut Department of Environmental Protection estimated atmospheric loadings to Long Island Sound by extrapolating measurements from Chesapeake Bay and the Great Lakes, and using local measurements reported in the literature and made by USGS for the DEP as part of the National Estuary Program.

Concentrations of metals are provided as means; standard deviations are shown in parentheses in the following sections.

Antimony

Atmospheric concentration of antimony is reported to be 0.5 ng/m3 by Zoller and Gordon (1970), 9.1(11) ng/m3 by Hopke et al. (1976) and 0.83(0.41) ng/m3 by Rahn et al. (1984). Analysis of data reported by Olmez (1990) results in an estimate of 1.1(2.2) ng/m3. The concentration used for antimony in the present analysis is 1.1(2.2) ng/m3 based on the data of Olmez (1990). It is the most recent and most extensive data set available. Except for the data of Hopke et al., it is the most representative of the study area.

Antimony is associated with emissions from coal combustion, incineration, and antimony roasting (Keeler and Samson, 1989). Hopke et al. (1976) identify an incinerator in Somerville as a possible source of pollution to Boston Harbor.

Deposition velocity of antimony is reported to be 0.06 to <0.4 cm/s by Sehmel (1980). The deposition velocity of metals reported by McMahon (1979) is usually at the lower end of the range reported by Sehmel (1980). Since McMahon does not report a deposition velocity for antimony, it is estimated to be 0.1 cm/s.

No data are available on the concentration of antimony in precipitation or on the washout ratio of antimony. Wet depositional flux is therefore not estimated.

The estimate of atmospheric loading of antimony to the Massachusetts Bays is presented in Table 71. Dry depositional flux is estimated to be 0.01 to 0.09 mg/m2/yr using the 10th and 90th percentiles of aerosol concentration. Total annual loading of antimony is estimated to be << (much less than) 1 metric ton/yr (46 to 333 kg/yr), based on dry deposition alone.

Table 71. Atmospheric loading of antimony (kg/yr) to Massachusetts Bays. Estimates include dry and wet deposition.

Area	Low Estimate	High Estimate
Mass Bay	28	200
Cape Cod Bay	16	118
Broad Sound	1	6
North Harbor	1	4
Quincy Bay	0	3
Inner Harbor	0	1
Hingham Bay	0	2
Total	46	333

Arsenic

Atmospheric concentration of arsenic is reported to be 0.5(2.1) ng/m3 by Olmez (1990). Rahn et al. (1984) measured concentrations of 0.49(0.15) ng/m3 and Walsh et al. (1979) measured concentrations of 1.9 ng/m3. Both these measurements were made in Rhode Island, the former in a rural area and the latter in an urban area (Providence). Scudlark and Church measured arsenic concentrations of 1.05 ng/m3 at Lewes, DE. The major source of arsenic is the upper Ohio River Valley and the Sudbury region of Ontario, Canada (Keeler and Samson, 1989). Arsenic is therefore not a local source and the concentration across the Massachusetts Bays is likely to be uniform. The concentration of 0.5(2.1) ng/m3 by Olmez was used in the present analysis. The 10th and 90th percentile are 0.2 and 1.3 ng/m3.

Deposition velocity of arsenic is reported to be 0.22 cm/s by McMahon (1979) and to be <0.1 to <0.6 cm/s by Sehmel (1980). The deposition velocity used for arsenic in the present analysis is 0.22 cm/s. The resulting dry deposition flux is 0.01 to 0.09 mg/m2/yr.

The washout ratio for arsenic is 110, according to McMahon (1979). This results in a wet deposition flux of 0.02 to 0.16 mg/m2/yr. The arsenic concentration in precipitation is 0.02 to 0.16 ug/l; this is much smaller than the 0.58 ug/l that Galloway et al. (1982) report for generic urban areas.

The estimate of atmospheric loading of arsenic to the Massachusetts Bays is presented in Table 72. Total annual loading of arsenic is estimated to be about <1 metric ton per year.

Table 72. Atmospheric loading of arsenic (kg/yr) to Massachusetts Bays. Estimates include dry and wet deposition.

Area	Low Estimate	High Estimate
Mass Bay	87	557
Cape Cod Bay	51	329
Broad Sounds	17	
North Harbor	2	10
Quincy Bay	2	10
Inner Harbor	0	3
Hingham Bay	1	5
Total	145	930

Cadmium

Very few data are available on the atmospheric concentration of cadmium in the northeast U.S. Olmez (1990) reported nine measurements, most of which are below detection. The lowest detectable concentration that he reports is 2.4 ng/m3, which was used in the present analysis as the high end of the range of concentration.

Deposition velocity of cadmium is reported to be 0.45 cm/s by McMahon (1979) and to be <0.4 to >8 cm/s by Sehmel (1980). The deposition velocity used for cadmium in the present analysis is 0.45 cm/s. Dry deposition flux is estimated to be 0.34 mg/m2/yr.

The washout ratio for cadmium is 125, according to McMahon (1979), resulting in a wet concentration of 0.30 ug/l using the Olmez data. Concentration of cadmium in rainfall was measured to be 0.31 ug/l at Woods Hole, Massachusetts. Reported wet concentrations of 2.3 ug/l by Galloway et al. (1982) for a generic urban area are too high to be representative of the study area.

Wet deposition based on the above concentrations are 0.34 mg/m2/yr.

The estimate of atmospheric loading of cadmium to the Massachusetts Bays is presented in Table 73. Total annual loading of cadmium is estimated to be 3 metric tons/yr.

Table 73. Atmospheric loading of cadmium (kg/yr) to Massachusetts Bays. Estimates include dry and wet deposition.

Area	Low Estimate	High Estimate
Mass Bay	0	1499
Cape Cod Bay	0	886
Broad Sound	0	45
North Harbor	0	28
Quincy Bay	0	26
Inner Harbor	0	7
Hingham Bay	0	13
Total	0	2504

Chromium

Atmospheric concentration of chromium is reported to be 3.4(5.5) ng/m3 by Hopke et al. (1976). Analysis of the data provided by Olmez (1990) results in 0.7(4.0) ng/m3. The estimates from the Olmez data set is used in the present analysis with 10th and 90th percentiles of 0.1 and 4.3 ng/m3 respectively.

Deposition velocity of chromium is reported to be 0.5 cm/s by McMahon (1979) and to be 0.6 to 6.8 cm/s by Sehmel (1980). The deposition velocity used for chromium in the present analysis is 0.5 cm/s. This results in a dry deposition flux of 0.02 to 0.68 mg/m2/yr.

The washout ratio for chromium is 150, according to McMahon (1979). This results in a wet deposition flux of 0.02 to 0.71 mg/m2/yr. This flux corresponds to the low end of the range of urban wet concentrations reported by Galloway et al. (1982), 0.51 to 15 ug/l.

The estimate of atmospheric loading of chromium to the Massachusetts Bays is presented in Table 74. Total annual loading of chromium is estimated to be <6 metric tons/yr.

Table 74. Atmospheric loading of chromium (kg/yr) to Massachusetts Bays. Estimates include dry and wet deposition.

Area	Low Estimate	High Estimate
Mass Bay	87	3062
Cape Cod Bay	51	1810
Broad Sound	3	92
North Harbor	2	57
Quincy Bay	1	53
Inner Harbor	0	14
Hingham Bay	1	14
Total	145	5114

Cobalt

Atmospheric concentration of cobalt is reported to be 0.2 ng/m3 by Zoller and Gordon (1970), 0.62 to 2.3 ng/m3 by Gladney et al. (1974) and 1.00 (0.70) ng/m3 by Hopke et al. (1976). Analysis of the data provided by Olmez (1990) results in estimates of 0.3(3.1) ng/m3. The 10th and 90th percentiles of the Olmez data, 0.08 and 1.5 ng/m3, are used.

Deposition velocity of cobalt is reported to be to be 0.3 to 1.9 cm/s by Sehmel (1980). The deposition velocity used for cobalt in the present analysis is 0.3 cm/s, consistent with the deposition velocity selected for other metals which are at the low end of the range reported by Sehmel (1980). This deposition velocity results in a dry deposition flux of 0.01 to 0.14 mg/m2/yr.

No data are available on the washout ratio of cobalt. The wet deposition of cobalt is estimated from the urban concentration of cobalt in precipitation reported by Galloway et al. (1982), 1.8 ug/l. This results in a wet depositional flux of 1.98 mg/m2/yr.

The estimate of atmospheric loading of cobalt to the Massachusetts Bays is presented in Table 75. Total annual loading of cobalt is estimated to be 8 to 9 metric tons/yr. Most of this loading is due to wet deposition, which is based on summary data for urban areas and do not include data specific to eastern Massachusetts. Dry deposition is based on data from the Boston area, and constitutes < 1 metric ton/year of loading, which is probably a more representative estimate.

Table 75. Atmospheric loading of cobalt (kg/yr) to Massachusetts Bays. Estimates include dry and wet deposition.

Area	Low Estimate	High Estimate
Mass Bay	4373	4662
Cape Cod Bay	2584	2755
Broad Sound	131	140
North Harbor	82	87
Quincy Bay	76	81
Inner Harbor	20	21
Hingham Bay	38	40
Total	7303	7786

Copper

Atmospheric concentration of copper is reported to be 50 ng/m3 by Zoller and Gordon (1970) according to their own measurements; they also report a value of 110 ng/m3 as measured by the U.S. Public Health Service in Somerville. Thurston and Spengler (1985) measured fine and coarse concentrations of copper of 16.1 and 10.4 ng/m3, respectively. The fine concentration measured by Thurston and Spengler (1985), 16.1 ng/m3, is used.

Deposition velocity of copper is reported to be 0.5 cm/s by McMahon (1979) and to be <0.6 to 1.1 cm/s by Sehmel (1980). The deposition velocity used for copper in the present analysis is 0.5 cm/s. This results in a dry deposition flux of 2.5 to 8.4 mg/m2/yr.

The washout ratio for copper is 140, according to McMahon (1979). This results in a wet deposition flux of 2.5 mg/m2/yr. This flux is lower than the low end of the range of urban wet concentrations reported by Galloway et al. (1982), 6.8 to 120 ug/l.

The estimate of atmospheric loading of copper to the Massachusetts Bays is presented in Table 76. Total annual loading of copper is estimated to be 20 metric tons/yr, lower than estimates for Long Island Sound (29 to 78 metric tons/yr; Connecticut Department of Environmental Protection, 1987).

Table 76. Atmospheric loading of copper (kg/yr) to Massachusetts Bays. Estimates include dry and wet deposition.

Area	Low Estimate	High Estimate
Mass Bay		11040
Cape Cod Bay		6523
Broad Sound		331
North Harbor		206
Quincy Bay		191
Inner Harbor		50
Hingham Bay		95
Total		18436

Iron

Atmospheric concentration of iron is reported to be 1000 to 1300 ng/m3 by Zoller and Gordon (1970) and to be 1090(1000) ng/m3 by Hopke et al. (1974). Thurston and Spengler (1985) report 74.7 and 281 ng/m3 for the fine and coarse fractions, respectively. Analysis of the data provided by Olmez (1990) results in a mean of 111 ng/m3 with 10th and 90th percentiles of 53 and 231 ng/m3. These estimates are used in the present analysis.

Deposition velocity of iron is reported to be 1.1 cm/s by McMahon (1979) and to be 1.0 to 2.5 cm/s by Sehmel (1980). The deposition velocity used for iron in the present analysis is 1.1 cm/s. This results in a dry deposition flux of 18.5 to 80.4 mg/m2/yr.

The washout ratio for iron is 250, according to McMahon (1979). Jaffrezo and Colin (1988) report a scavenging ratio which is equivalent to a washout ratio of 330, as defined by McMahon (1979). A washout ratio of 250 is used in the present analysis. This results in a wet deposition flux of 14.6 to 63.7 mg/m2/yr.

The estimate of atmospheric loading of iron to the Massachusetts Bays is presented in Table 77. Total annual loading of iron is estimated to be 134 to 584 metric tons/yr. The iron loading estimated for Long Island Sound, an area comparable in size to the Massachusetts Bays, is 1110 metric tons/yr (Connecticut Department of Environmental Protection).

Table 77. Atmospheric loading of iron (kg/yr) to Massachusetts Bays. Estimates include dry and wet deposition.

Area	Low Estimate	High Estimate
Mass Bay	72804	316977
Cape Cod Bay	43021	187304
Broad Sound	2184	9509
North Harbor	1357	5907
Quincy Bay	1258	5475
Inner Harbor	331	1441
Hingham Bay	629	2738
Total	121584	529351

Lead

Atmospheric concentration of lead is reported to be 326(13.2) ng/m3 for the fine fraction and 75.6(4.57) ng/m3 for the coarse fraction by Thurston and Spengler (1985). The fine concentration is used in the present analysis.

Deposition velocity of lead is reported to be 0.3 cm/s by McMahon (1979). This deposition velocity is used in the present analysis. This results in a dry deposition flux of 30.8 mg/m2/yr.

The washout ratio for lead is 76, according to McMahon (1979). This results in a wet deposition flux of 27 mg/m2/yr.

The estimate of atmospheric loading of lead to the Massachusetts Bays is presented in Table 78. The annual loading of lead is estimated to be 235 metric tons/yr. The lead loading estimated for Long Island Sound is 628 metric tons/yr (Connecticut Department of Environmental Protection), much higher than the estimate for Massachusetts Bays. Connecticut also reports a wet depositional loading of 30 metric tons/yr, measured by USGS. The wet loading to Massachusetts Bays is estimated to be 110 tons/yr. This comparison suggests that the estimates for Massachusetts Bays may be low. Other data sources for the atmospheric concentration of lead and for the washout ratio for lead should be sought to resolve this question.

Table 78. Atmospheric loading of lead (kg/yr) to Massachusetts Bays. Estimates include dry and wet deposition.

Area	Low Estimate	High Estimate
Mass Bay		127811
Cape Cod Bay		75525
Broad Sound		3834
North Harbor		2382
Quincy Bay		2208
Inner Harbor		581
Hingham Bay		1104
Total		213444

Manganese

Atmospheric concentration of manganese is reported to be 10 to 50 ng/m3 by Zoller and Gordon (1970) and 27(19) ng/m3 by Hopke et al. (1974). Thurston and Spengler (1985) report 3.61 and 5.81 ng/m3 for the fine and coarse size fractions, respectively. Rahn and Lowenthal (1984) report non-crustal manganese concentrations of 4.2(0.8) ng/m3 at Narragansett during winds from the direction of Boston. The data provided by Olmez (1990) results in a mean of 3.7 ng/m3 with 10th and 90th percentiles of 1.8 and 7.3 ng/m3, respectively. These estimates are used in the present analysis.

Deposition velocity of manganese is reported to be 0.56 cm/s by McMahon (1979) and to be 0.4 to 0.9 cm/s by Sehmel (1980). The deposition velocity used for manganese in the present analysis is 0.56 cm/s. This results in a dry deposition flux of 0.3 to 1.3 mg/m2/yr.

The washout ratio for manganese is 370, according to McMahon (1979). This results in a wet deposition flux of 0.7 to 3.0 mg/m2/yr. This flux corresponds to the low end of the range of urban wet concentrations reported by Galloway et al. (1982), 1.9 to 80 ug/l.

The estimate of atmospheric loading of manganese to the Massachusetts Bays is presented in Table 79. Total annual loading of manganese is estimated to be 4 to 17 metric tons/yr. The total manganese loading estimated for Long Island Sound is 22.2 metric tons/yr (Connecticut Department of Environmental Protection, 1987).

Table 79. Atmospheric loading of manganese (kg/yr) to Massachusetts Bays. Estimates include dry and wet deposition.

Area	Low Estimate	High Estimate
Mass Bay	2338	9433
Cape Cod Bay	1382	5580
Broad Sound	70	283
North Harbor	44	176
Quincy Bay	40	163
Inner Harbor	11	43
Hingham Bay	20	82
Total	3905	15770

Mercury

No data are available for the atmospheric concentration of mercury in the Massachusetts Bays region.

No data are available on the deposition velocity of mercury.

No data are available on the washout ratio of mercury. The concentration of mercury in precipitation was measured directly by Fogg and Fitzgerald (1979), 6 to 18 ng/l.

The estimate of atmospheric loading of mercury to the Massachusetts Bays is presented in Table 80 and in the Appendix. Total annual loading of mercury is estimated to be 24 to 73 kg/yr.

Table 80. Atmospheric loading of mercury (kg/yr) to Massachusetts Bays. Estimates include dry and wet deposition.

Area	Low Estimate	High Estimate
Mass Bay	15	44
Cape Cod Bay	9	26
Broad Sound	0	1
North Harbor	0	1
Quincy Bay	0	1
Inner Harbor	0	0
Hingham Bay	0	0
Total	24	73

Molybdenum

The data provided by Olmez (1990) result in a mean concentration of 0.6 ng/m3 with 10th and 90th percentiles of 0.2 and 1.8 ng/m3, respectively. However, no data are available on the deposition velocity of molybdenum, therefore no estimate is made for dry deposition loading of molybdenum.

No data is available on the washout ratio of molybdenum. The concentration of molybdenum in precipitation is taken from the summary of Galloway et al. (1982) for urban areas, 0.2 ug/l. This results in a wet deposition flux of 0.22 mg/m2/yr.

The estimate of atmospheric loading of molybdenum to the Massachusetts Bays is presented in Table 81. Total annual loading of molybdenum is estimated to be < 1 metric ton/yr, based on wet deposition alone.

Table 81. Atmospheric loading of molybdenum (kg/yr) to Massachusetts Bays. Estimates include only wet deposition.

Area	Low Estimate	High Estimate
Mass Bay		484
Cape Cod Bay		286
Broad Sound		15
North Harbor		9
Quincy Bay		8
Inner Harbor		2
Hingham Bay		4
Total		808

Nickel

Atmospheric concentration of nickel is reported to be 52 ng/m3 by Zoller and Gordon (1970). Thurston and Spengler (1985) report 8.57(0.39) and 2.44(0.13) ng/m3 for the fine and coarse fractions, respectively. The fine fraction concentration measured by Thurston and Spengler (1985), 8.57 ng/m3, is used in the present analysis.

Deposition velocity of nickel is reported to be 0.45 cm/s by McMahon (1979) and to be 0.7 to <2 cm/s by Sehmel (1980). The deposition velocity used for nickel in the present analysis is 0.7 cm/s. This results in a dry deposition flux of 1.9 mg/m2/yr.

The washout ratio for nickel is 125, according to McMahon (1979). This results in a wet deposition flux of 1.2 mg/m2/yr.

The estimate of atmospheric loading of nickel to the Massachusetts Bays is presented in Table 82 and in the Appendix. The total annual loading of nickel is estimated to be 12 metric tons/yr, 5 metric tons/yr for wet deposition. The loading from wet deposition estimated for Long Island Sound is 8 tons/yr (Connecticut Department of Environmental Protection, 1987), slightly below the estimate for Massachusetts Bays.

Table 82. Atmospheric loading of nickel (kg/yr) to Massachusetts Bays. Estimates include dry and wet deposition.

Area	Low Estimate	High Estimate
Mass Bay		6754
Cape Cod Bay		3991
Broad Sound		203
North Harbor		126
Quincy Bay		117
Inner Harbor		31
Hingham Bay		58
Total		11280

Selenium

Atmospheric concentration of selenium is reported to be 0.6 ng/m3 by Zoller and Gordon (1970), 1.4 to 4.9 ng/m3 by Gladney et al. (1974) and 1.23(1.23) ng/m3 by Hopke et al. (1974). Thurston and Spengler (1985) report 0.595(0.46) for the fine size fraction; no coarse fraction was detected. Rahn and Lowenthal (1984) report selenium concentrations of 1.00(0.60) ng/m3 at Narragansett, Rhode Island during winds from the direction of Boston. The data provided by Olmez (1990) results in an estimated mean concentration of 0.7 ng/m3 with 10th and 90th percentiles of 0.2 and 2.6 ng/m3, respectively. These values are used in the present analysis. The data from Rahn and Lowenthal (1984), suggest that these values are likely representative of the entire study area.

Deposition velocity of selenium is reported to be 0.1 to 0.6 cm/s by Sehmel (1980). The deposition velocity used for selenium in the present analysis is 0.1 cm/s; this is consistent with the selection of deposition velocity for other metals, i.e. choosing from the lower limit reported by Sehmel (1980). This deposition velocity results in a dry deposition flux of <0.01 to 0.08 mg/m2/yr.

No data is available on the washout ratio of selenium. No data is available on the concentration of selenium in wet deposition, either specifically for the Massachusetts Bays region or for generic urban, rural, or marine regions. No wet deposition can be estimated for selenium in the present analysis.

The estimate of atmospheric loading of selenium to the Massachusetts Bays is presented in Table 83. Total annual loading of selenium is estimated to be <<1 metric ton/yr. This estimate is based on dry deposition only.

Table 83. Atmospheric loading of selenium (kg/yr) to Massachusetts Bays. Estimates include only dry deposition.

Area	Low Estimate	High Estimate
Mass Bay	14	182
Cape Cod Bay	8	108
Broad Sound	0	5
North Harbor	0	3
Quincy Bay	0	3
Inner Harbor	0	1
Hingham Bay	0	2
Total	23	305

Silver

Very few aerosol data are available for silver. Olmez (1990) reports a maximum concentration of 1 ng/m3 for silver; most samples were below detection. A concentration of 0.2 ng/m3 is used, based on Olmez data.

Deposition velocity of silver is reported to be 0.24 cm/s by McVeety and Hites (1988) and 0.1 to 0.6 cm/s by Sehmel (1980). The deposition velocity assumed for silver in the present analysis is 0.24 cm/s. This results in a dry depositional flux of 0.02 mg/m2/yr.

No data are available on the washout ratio of silver. The concentration of silver in precipitation is taken from the summary of Galloway et al. (1982) for urban areas, 3.2 ug/l. This results in a wet deposition flux of 3.5 mg/m2/yr. This estimate may not be representative of the study area.

The estimate of atmospheric loading of silver to the Massachusetts Bays is presented in Table 84 and in the Appendix. Total annual loading of silver is estimated to be 14 metric tons/yr. This estimate is dominated by the wet concentration of silver in generic urban areas, not on data specific to the Massachusetts Bays region. The total silver loading estimated for Long Island Sound is 5.23 metric tons/yr (Connecticut Department of Environmental Protection, 1987), which may indicate that the estimate of silver loading for Massachusetts Bays is too high.

Table 84. Atmospheric loading of silver (kg/yr) to Massachusetts Bays. Estimates include dry and wet deposition.

Area	Low Estimate	High Estimate
Mass Bay		7777
Cape Cod Bay		4596
Broad Sound		233
North Harbor		145
Quincy Bay		134
Inner Harbor		35
Hingham Bay		67
Total		12988

Vanadium

Atmospheric concentration of vanadium is reported to be 13.18 ng/m3 by Rahn (1981) and 35(6) ng/m3 by Rahn and Lowenthal (1984) measured at Narragansett, RI during winds from the Boston direction. Thurston and Spengler (1985) reported concentrations of 22.1(1.10) and 3.34(0.33) ng/m3 for the fine and coarse size fractions respectively. Data provided by Olmez (1990) have a mean concentration of 12.1 ng/m3 with 10th and 90th percentiles of 4.1 and 35.7 ng/m3, respectively. These values are used in the present analysis.

Measurements of atmospheric concentration of vanadium made in the 1960's and early 1970's (Gladney et al., 1974; Hopke et al. 1976) were as high as 2000 ng/m3. The source of this vanadium was local combustion of residual oil. Rahn (1981) notes that this is no longer an important source and that urban concentrations are generally under 100 ng/m3. The older reports of extremely high vanadium concentrations are no longer representative of present conditions.

Deposition velocity of vanadium is reported to be 0.29 cm/s by McMahon (1979) and 0.2 to <0.7 cm/s by Sehmel (1980). The deposition velocity used for vanadium in the present analysis is 0.29 cm/s. This deposition velocity results in a dry deposition flux of 0.4 to 3.3 mg/m2/yr.

The washout ratio for vanadium is 110, according to McMahon (1979). This results in a wet deposition flux of 0.4 to 4.3 mg/m2/yr. This flux corresponds to a wet deposition concentration well below the range reported by Galloway et al. (1982), 16 to 68 ug/l. The older measurements reported in the review article by Galloway are probably not representative of present conditions. The estimate of atmospheric loading of vanadium to the Massachusetts Bays is presented in Table 85. Total annual loading of vanadium is estimated to be 4 to 31 metric tons/yr.

Table 85. Atmospheric loading of vanadium to Massachusetts Bays. Estimates include dry and wet deposition.

Area	Low Estimate	High Estimate
Mass Bay	1909	16668
Cape Cod Bay	1128	9850
Broad Sound	57	500
North Harbor	36	311
Quincy Bay	33	288
Inner Harbor	9	76
Hingham Bay	16	144
Total	3188	27836

Zinc

Atmospheric concentration of zinc is reported to be 100 to 210 ng/m3 by Zoller and Gordon (1970), 100 to 340 ng/m3 by Gladney et al. (1974) and 190(220) ng/m3 by Hopke et al. (1974). Thurston and Spengler (1985) report 26.5(1.05) and 12.2(0.64) ng/m3 for the fine and coarse size fractions, respectively. The data provided by Olmez (1990) has a mean concentration of 14.6 ng/m3 with 10th and 90th percentiles of 3.7 and 58.3 ng/m3, respectively. These values are used in the present analysis.

The concentrations reported by Thurston and Spengler (1985) and the measurements of Rahn and Lowenthal (1984) at Narragansett during winds from the direction of Boston are similar to the data of Olmez (1990), suggesting that these data are temporally and spatially representative of the entire study area.

Deposition velocity of zinc is reported to be 0.62 cm/s by McMahon (1979) and 0.4 to 4.5 cm/s by Sehmel (1980). The deposition velocity used for zinc in the present analysis is 0.62 cm/s. This deposition velocity results in a dry deposition flux of 0.7 to 11.4 mg/m2/yr. The washout ratio for zinc is 179, according to McMahon (1979). This results in a wet deposition flux of 0.7 to 11.5 mg/m2/yr.

The estimate of atmospheric loading of zinc to the Massachusetts Bays is presented in Table 86. Total annual loading of zinc is estimated to be 6 to 93 metric tons/yr. The total zinc loading estimated for Long Island Sound is 480 metric tons/yr (Connecticut Department of Environmental Protection, 1987), much larger than the estimate for Massachusetts Bays.

Table 86. Atmospheric loading of zinc to Massachusetts Bays. Estimates include dry and wet deposition.

Area	Low Estimate	High Estimate
Mass Bay	3153	50325
Cape Cod Bay	1863	29738
Broad Sound	95	1510
North Harbor	59	938
Quincy Bay	54	869
Inner Harbor	14	229
Hingham Bay	27	435
Total	5265	88043

Summary of atmospheric loading

Ranges in atmospheric loadings of chemicals to Massachusetts Bays are presented in Table 87.

Table 87. Atmospheric loading to the Massachusetts Bays (kg/yr).

Chemical	Total	References
Nutrients		
Nitrogen	1596150 - 4484822	M7 M8
Phosphorus	12486 - 51283	R6
Organics		
PAHs	953 - 1260	M6
PCB	745 - 2097	R5
Metals		
Sb	46- 333	M1 M2 M8 R1
As	145 - 930	M8 R1 R2
Cd	2504	M8 R3
Cr	145 - 5114	M2 M8
Co	7303 - 7786	M1 M2 M3 M8
Cu	18436	M1 M4
Fe	121584 - 529351	M1 M2 M4 M8
Pb	213444	M4
Mn	3905 - 15770	M1 M2 M4 M8
Hg	24 - 73	M5
Mo	808	M8 G1
Ni	11280	M4 R1 R4
Se	23 - 305	M1 M2 M3 M4 M8 R1
Ag	12988	M8 G1
V	3188 - 88043	M4 M8 R1 R2
Zn	5265 - 88043	M1 M2 M3 M4 M8 R1

References by area.
Massachusetts Bays: M1 (Zoller & Gordon, 1970); M2 (Hopke et al., 1976); M3 (Gladney et al., 1974); M4 (Thurston & Spengler, 1985); M5 (Fogg & Fitzgerald, 1974); M6 (US EPA AIRS, 1990); M7 (Galloway et al., 1987); M8 (NADP, 1989); M8 (Olmez, 1990).
New England Regional: R1 (Rahn & Lowenthal, 1984); R2 (Walsh et al., 1979); R3 (Galloway et al., 1982); R4 (Rahn, 1981); R5 (Harvey & Steinhauer, 1974); R6 (Conn. Dept. Environ. Protect., 1987).
Generic Urban Areas: G1 (Galloway, et al., 1982).

5.7 Spatial Distribution of Hazardous Waste Sites Near the Coast and Rivers

This section identifies DEP Confirmed Waste Disposal Sites and Locations To Be Investigated within 500 feet of Massachusetts coastal waters and the Merrimack River to Pawtucket Dam.

5.7.1 Approach

The following approach was used to identify the sites:

1. Streets and roadways within 500 feet of surface water bodies were identified using the "Universal Atlas of Metropolitan Boston and Eastern Massachusetts", 23rd Edition published in 1990 by Universal Publishing Company, Stoughton, MA and the "Universal Atlas of Cape Cod and Southeastern Massachusetts," 1st Edition published in 1988 by Universal Publishing Company.

2. The October 15, 1990 and November 1990 Northeast Region Sites database was reviewed. This is a DEP inhouse database of all Environmental Site Assessment Reports on file with the Northeast Office of the DE in Woburn, MA. Properties located within 500 feet of coastal or Merrimack River surface waters were identified.

3. The September, 1990 and December 1990 Southeast Region Sites Database were reviewed. This inventory is maintained at the Southeast Office of the DEP in Lakeville, MA. Properties within 500 feet of surface waters were identified.

4. The July 15, 1990 and January 15, 1991 "List of Confirmed Disposal Sites and Locations To Be Investigated" was reviewed for possible additional sites.

5. Pertinent reports at the Northeast and Southeast Region Offices of the DEP were reviewed in order to determine the exact locations of properties for plotting on USGS maps.

6. Site visits were made to certain locations in Newburyport, Methuen, Amesbury, Andover, North Andover, Lowell, and Lawrence, MA, in order to determine if selected properties were located within 500 feet of Massachusetts coastal waters or tributaries.

7. Sites were classified in the following ways: (A) Former Coal Gasification Plants; (B) Tanneries and Factories; (C) Gasoline Stations and Miscellaneous Unknown Usage (Commercial Sites).

8. All sites were classified by town, by drainage basin, and by contaminant (H-hazardous materials, P-petroleum, UNK-unknown, not specified).

9. All sites identified within 500 feet of coastal surface waters or the Merrimack River were plotted on USGS maps and also on a computer-aided design (CAD) drawing of coastal Massachusetts.

5.7.2 Results

Sites identified within 500 feet of coastal waters or the Merrimack River illustrated on Figure 10. Figure 10 shows how the sites are grouped along the Merrimack River, in the greater Boston area, and in several smaller clusters. Details about the sites are presented in Appendix C. Within Appendix C, drainage basins are identified as follows:

ME: Merrimack River	WF: Weymouth Fore
NS: North Shore Coastal	WB: Weymouth Back
IP: Ipswich River	MB: Massachusetts Bay
SS: South Shore Coastal	MS: Mystic River

Some municipalities were found to be free of sites within 500 feet of Massachusetts coastal water ways and along the Merrimack River. The abbreviation N/A (not applicable) is referenced in Appendix B for each of these.

A total of 239 Confirmed Waste Sites were found to be located within 500 feet of the coast or Merrimack River. Most of these are located in the northern part of the state. Relatively few sites were found along the South Shore drainage area or on Cape Cod.

Sites were dominated by commercial facilities including gasoline stations. Tanneries and factories made up the next most prevalent category. Finally, there were four sites identified as former coal gasification facilities. Petroleum-related contamination was identified at 177 sites and hazardous materials were identified at 65 sites.

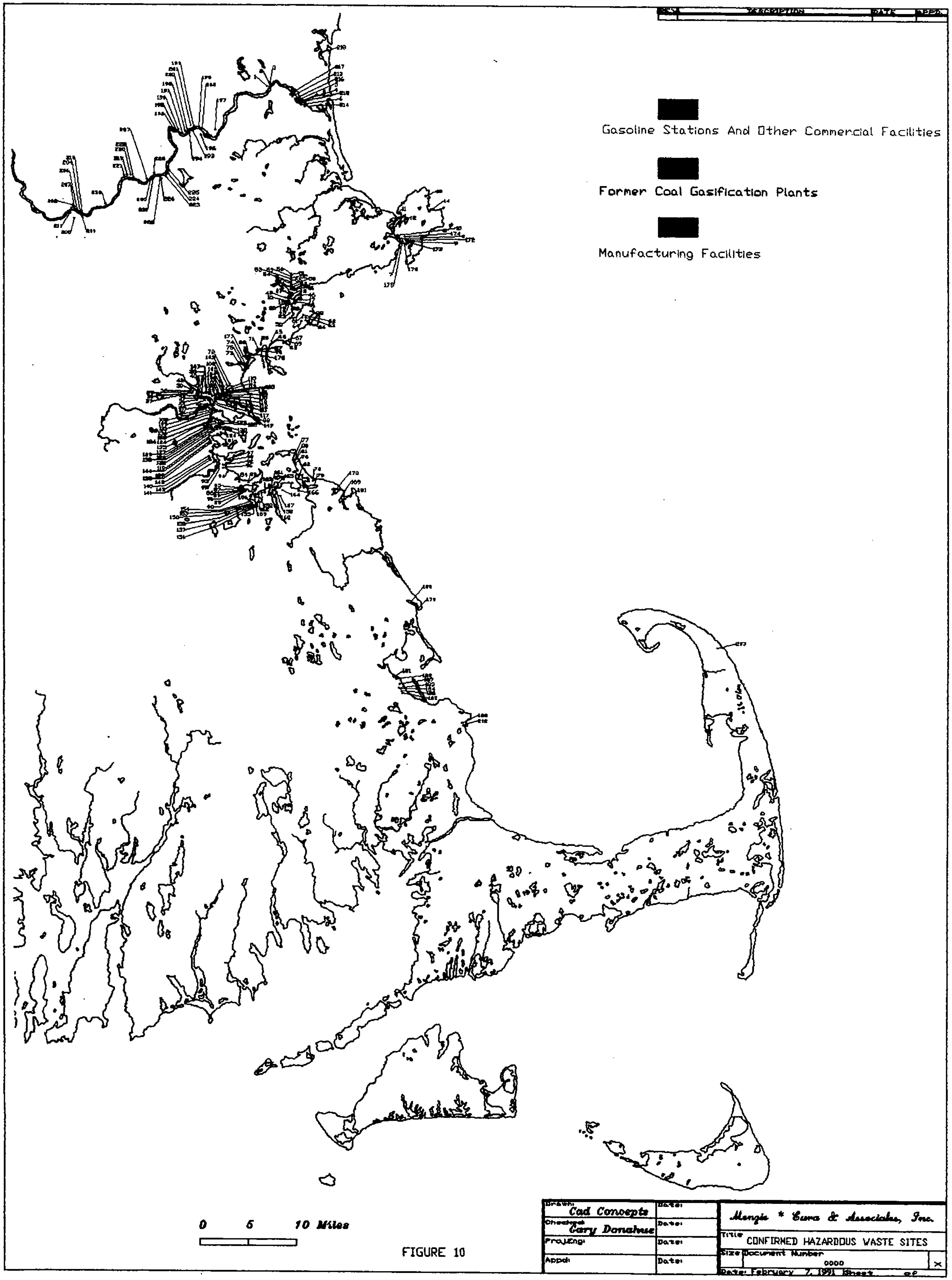

Gasoline Stations And Other Commercial Facilities
Former Coal Gasification Plants
Manufacturing Facilities
0 5 10 Miles
Drawn: Cad Concepts
Checked: Gary Donahue
Menzie * Cura & Associates, Inc.
Title CONFIRMED HAZARDOUS WASTE SITES
Size Document Number
0000
Date: February 7, 1991

FIGURE 10

5.8 In-Place Sediments

This section describes the status of knowledge about the quality of the sediments in Massachusetts Bay. The data are the results of core and grab sample analyses reported in various sources including both the scientific and the gray literature. Many of the coastal data were derived from regulation-driven sampling relating to the sites of sewage treatment plants or dredging activity. The samples taken were analyzed for various chemical constituents depending on the purpose of the study, thus, results for any subarea will tend to be weighted by a particularly heavy sampling effort due to a specific study. These data sources are described in Appendix B. The nature of the data are, therefore, not representative of the sediments throughout any particular system. Since the majority of sampling within the bay has been driven by the search for answers to environmental questions, the data may indicate that the extent of contamination is greater than reality.

To facilitate analysis and discussion of the data we have divided the study area by drainage basin and added two further subareas, the harbor and the bay. Data included in the drainage basin subarea is for coastal sampling stations. Table 88 shows the distribution of samples within each subarea.

Table 88. Distribution of sediment samples examined for this report.

Subarea (Drainage Basin)	Number of Samples
North Shore	20
Boston Harbor	193
Bay (including Cape Cod)	101
TOTAL	314

Each subarea will be discussed in a sub-section of this report. Each subsection will contain a description of the area, sample availability and sources, metals, organics, PCB and pesticides.

For metals,the sediments will be discussed in terms of the Massachusetts Criteria for Classification of Dredged or Fill Material (314 CMR 9.00, Certification for Dredging, Dredged Material Disposal and Filling in Waters). Three categories are provided, category I being the least contaminated, category III being most contaminated. Sediments will be classified in terms of PCB, pesticide and PAH content. With regard to total PAH concentrations, three levels were identified for classification purposes: < 10 mg/kg, 10 mg/kg to 100 mg/kg, greater than 100 mg/kg.

The locations of sediments exhibiting elevated levels of chromium, lead, and PAHs throughout the system are illustrated in Figures 11 to Figure 13. These figures are somewhat qualitative in nature but are intended to show those areas where bulk concentrations of compounds are generally elevated. Such areas may be considered to represent potential "hot spots". Based on our review of available data there appeared to be locations within the Boston Inner Harbor and Mystic River system where elevated levels of contaminants occurred. These data are summarized in Figures 14 through 24.

5.8.1 North Shore

Description

The North Shore Drainage Basin extends from Castle Neck in the North East to Swampscott in the South West. The major coastal centers of population and industry are Gloucester, Beverly, Salem and Marblehead. The available data for this sub-area are presented in Appendix C.

Metals

Of the twenty samples collected, eleven were classified as category III, six as category II, and the remaining three samples as category I. Several of the Salem Harbor samples contained high levels of chromium, this metal is associated with the hide tanning industry which was important in Salem's early industrial history.

Organic Compounds

PAHs were analyzed in only one sample set, the Salem Harbor Tier II Chemical evaluation report. PAHs were analyzed for samples from eight stations. Two of these exhibited PAH levels in excess of 10 mg/kg; none exceeded 100 mg/kg.

Pesticides

Pesticides were not measured in any of the samples taken. PCBs were measured in sixteen samples, of these the highest concentration was 0.03 mg/kg. Pesticides were measured in nine samples, but none were detected.

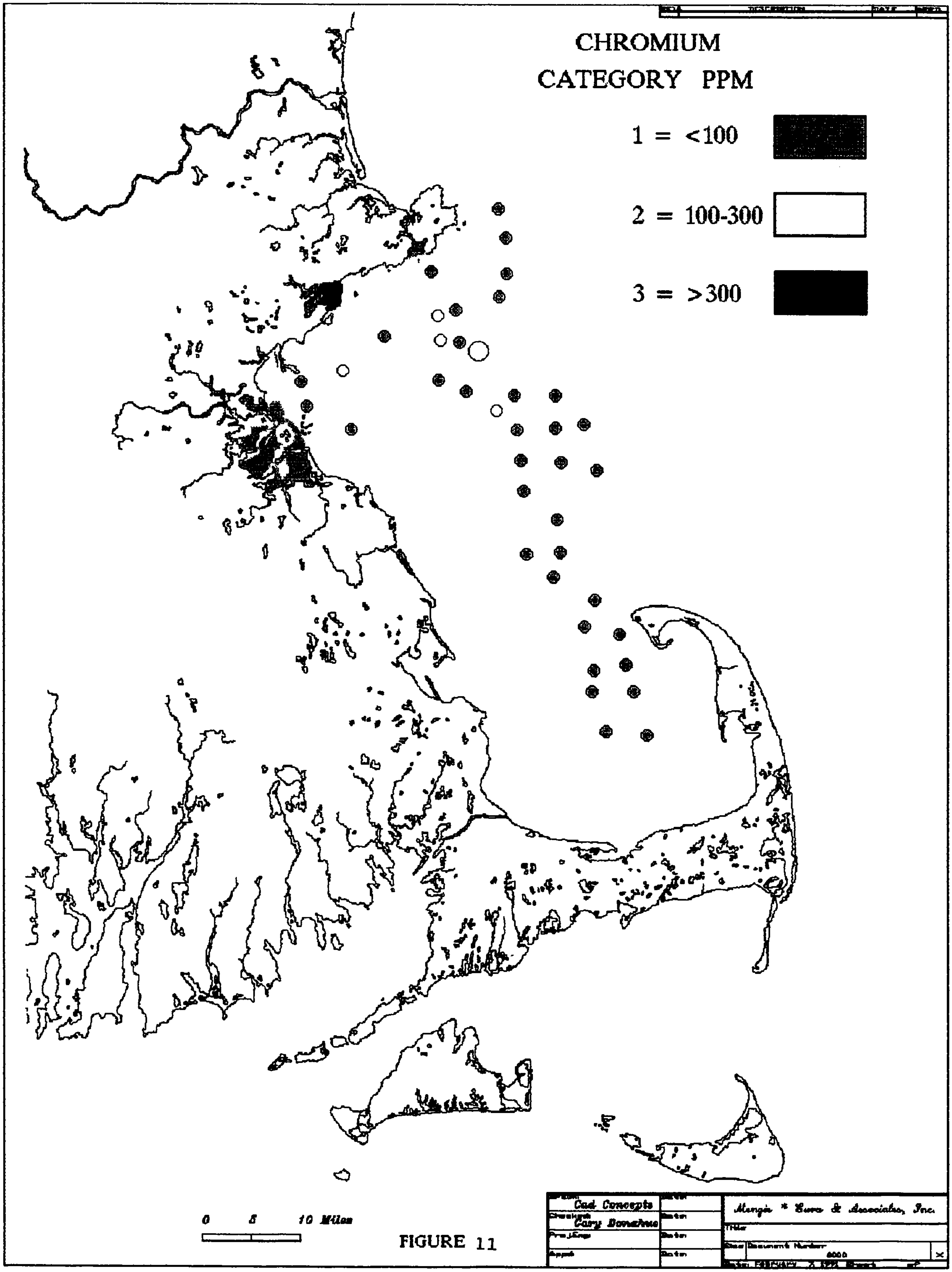
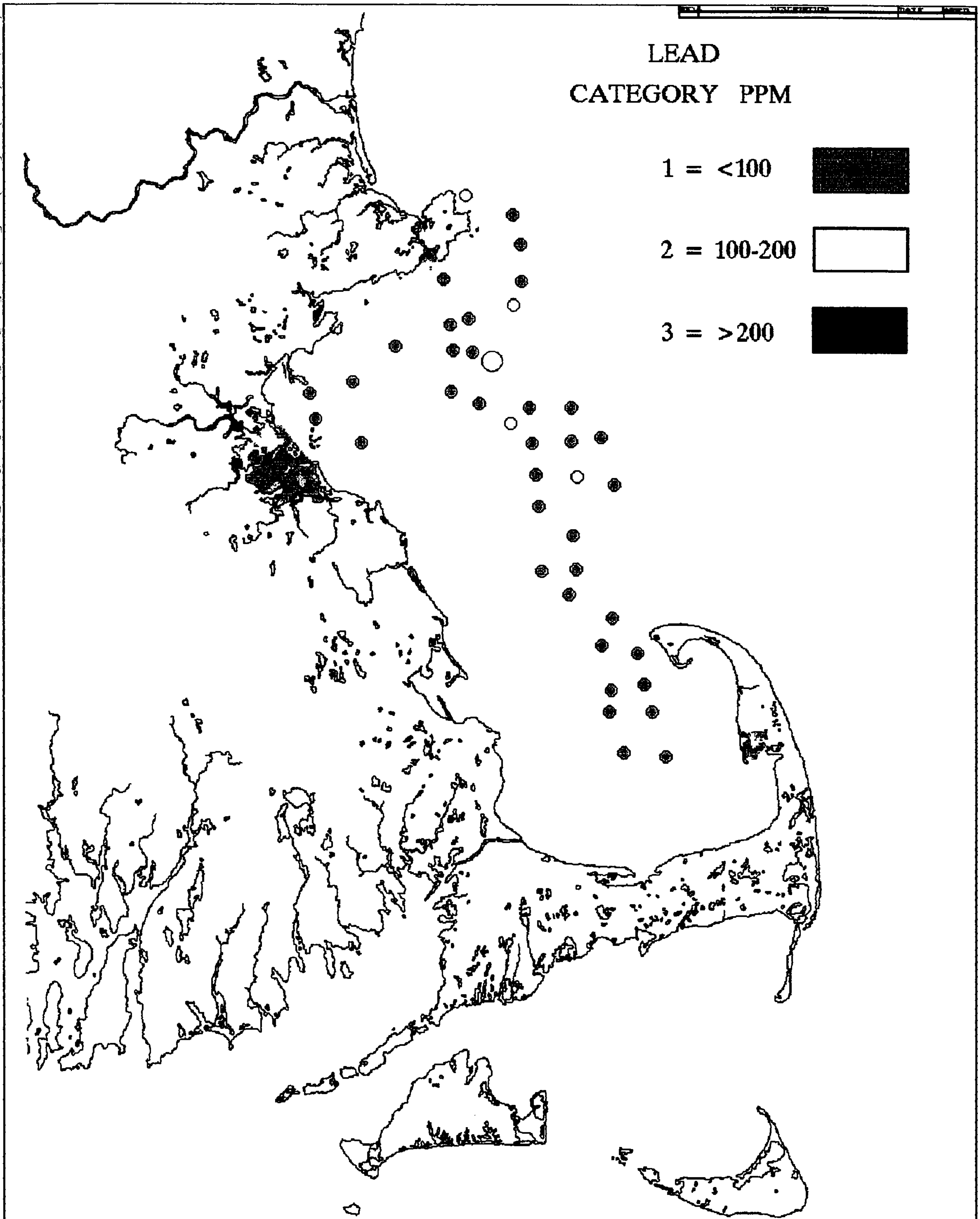

CHROMIUM
CATEGORY PPM
1 = <100
2 = 100-300
3 = >300
0 5 10 Miles
Cad Concepts
Cary Donahue
Mingin * Curo & Associates, Inc.
Title
Document Number

FIGURE 11



0 5 10 Miles

FIGURE 12

Cad Concepts
Gary Donahue
Menzie * Cura & Associates, Inc.
Document Number
Date: February

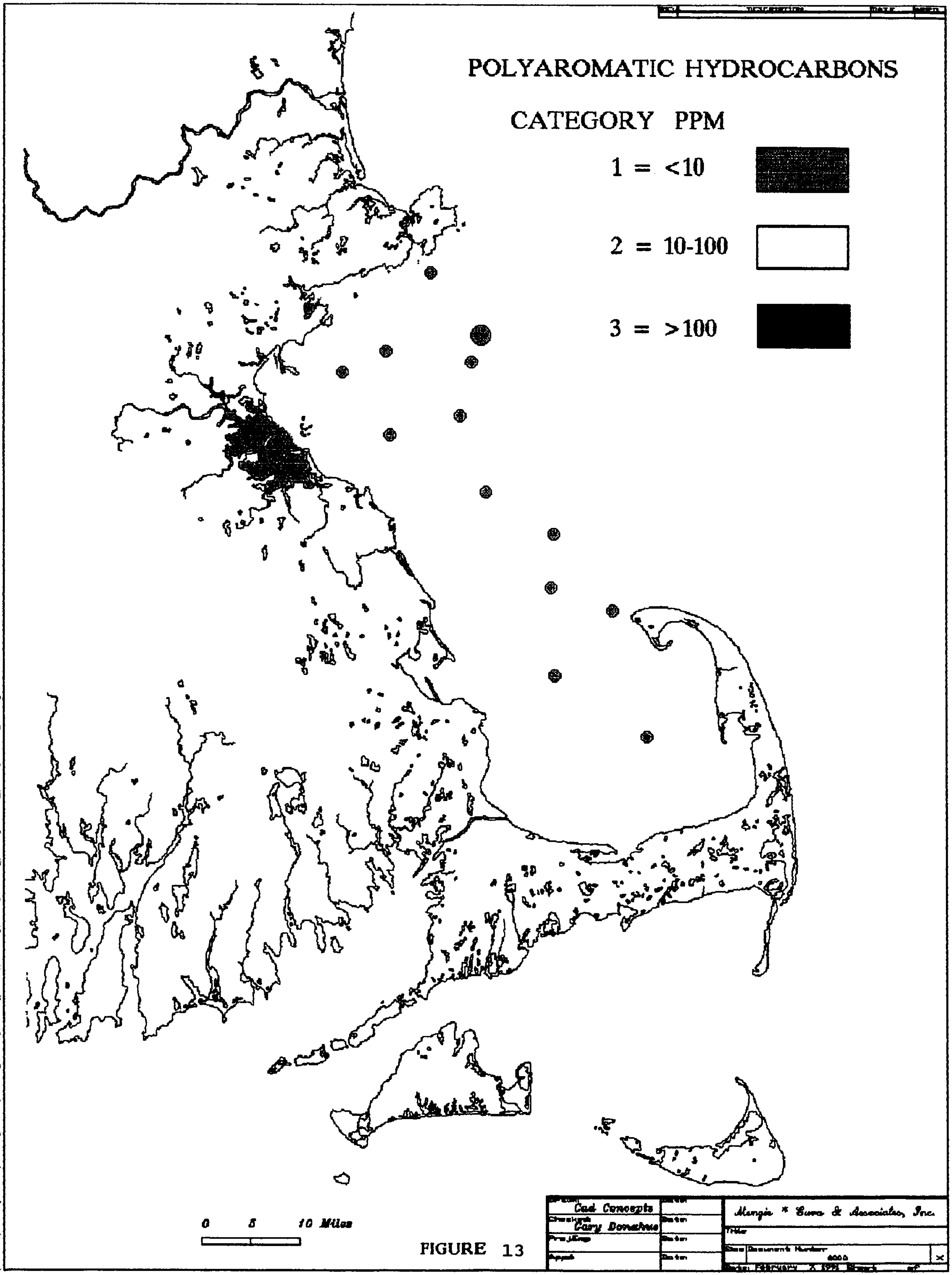

POLYAROMATIC HYDROCARBONS
CATEGORY PPM
1 = <10
2 = 10-100
3 = >100
0 5 10 Miles
Cad Concepts
Gary Donahue
Menzie * Cura & Associates, Inc.

FIGURE 13

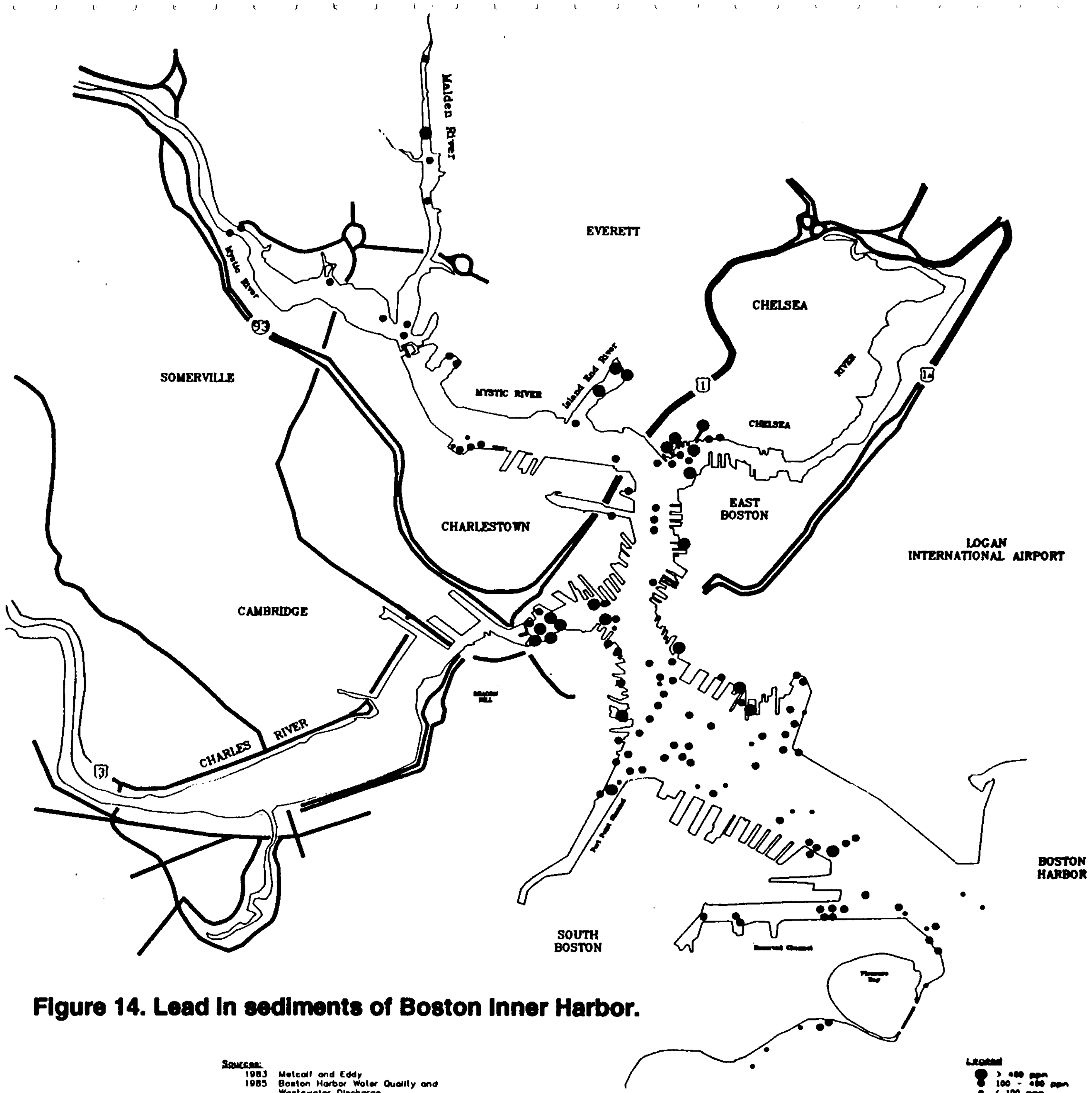


Figure 14. Lead in sediments of Boston Inner Harbor.

Sources:
1983 Metcalf and Eddy
1985 Boston Harbor Water Quality and Wastewater Discharge Data – MA DEQE DWPC
1987 Sanford Ecological Services, Inc
1988 DEQE Historical/ Field Investigation Report (Wehran Engineering)

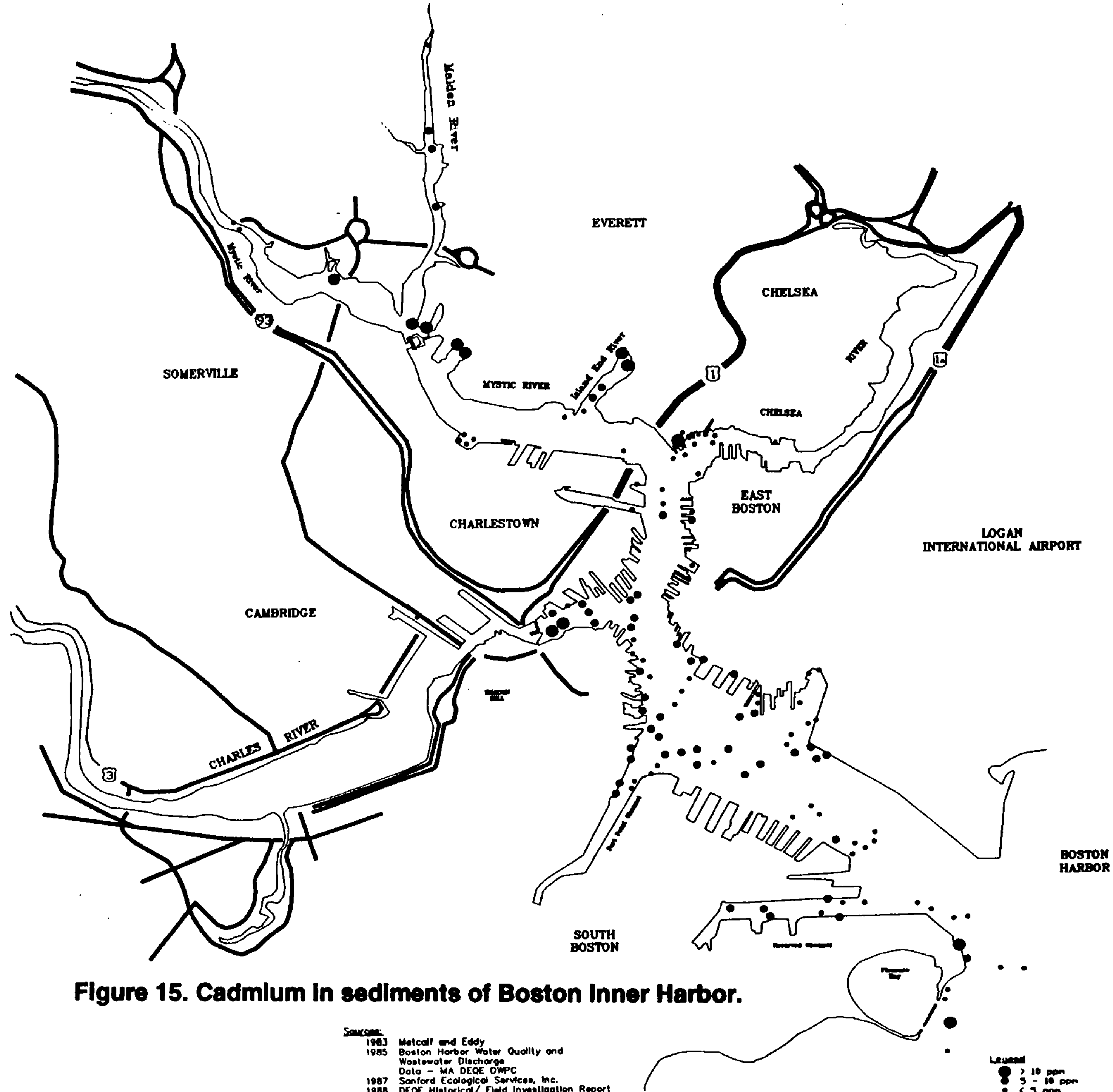


Figure 15. Cadmium in sediments of Boston Inner Harbor.

Sources:
1983 Metcalf and Eddy
1985 Boston Harbor Water Quality and Wastewater Discharge Data – MA DEQE DWPC
1987 Sanford Ecological Services, Inc.
1988 DEQE Historical/ Field Investigation Report (Wehran Engineering)

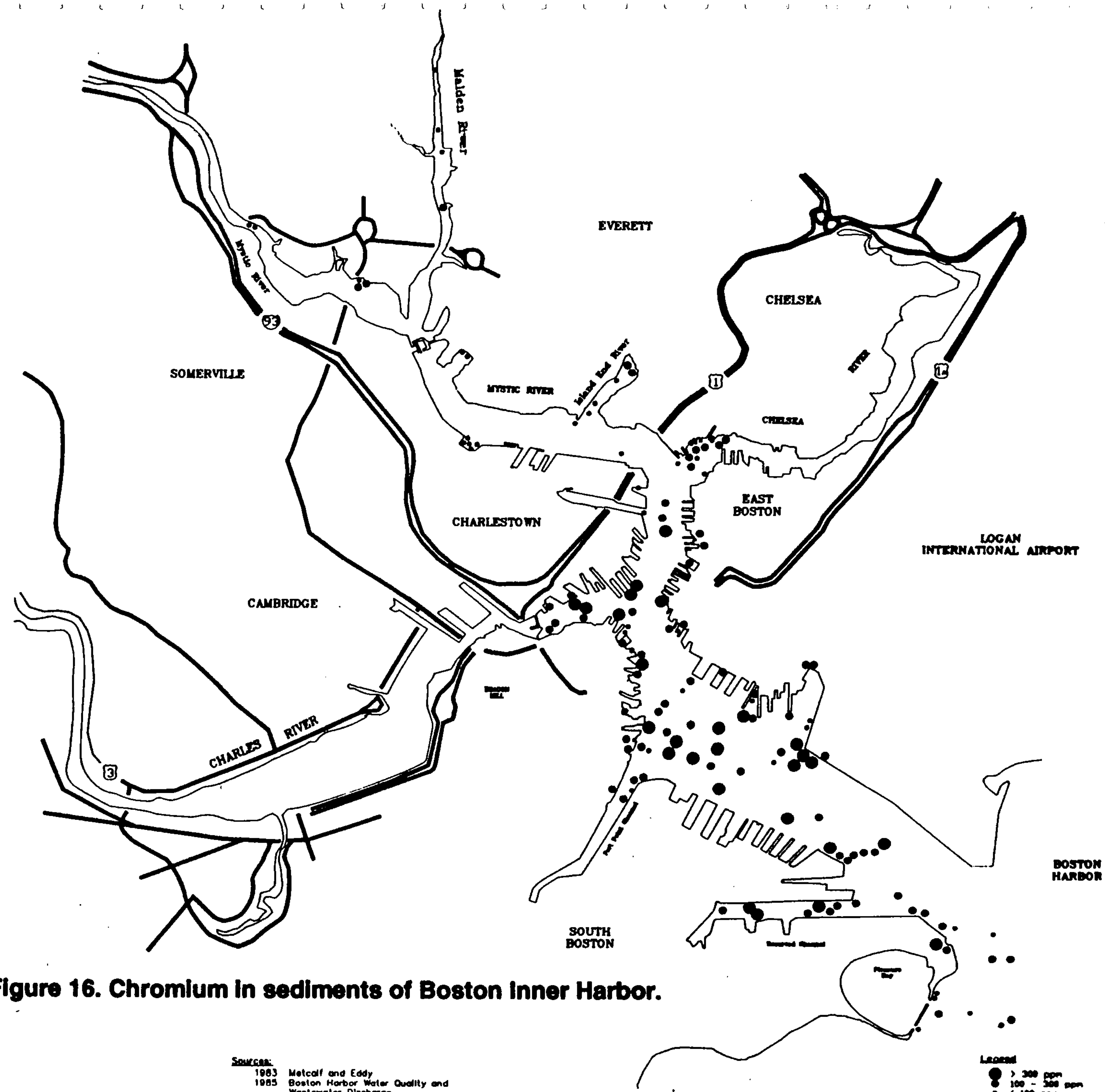


Figure 16. Chromium in sediments of Boston Inner Harbor.

Sources:
1983 Metcalf and Eddy
1985 Boston Harbor Water Quality and Wastewater Discharge Data – MA DEQE DWPC
1987 Sanford Ecological Services, Inc.
1988 DEQE Historical/ Field Investigation Report (Wehran Engineering)

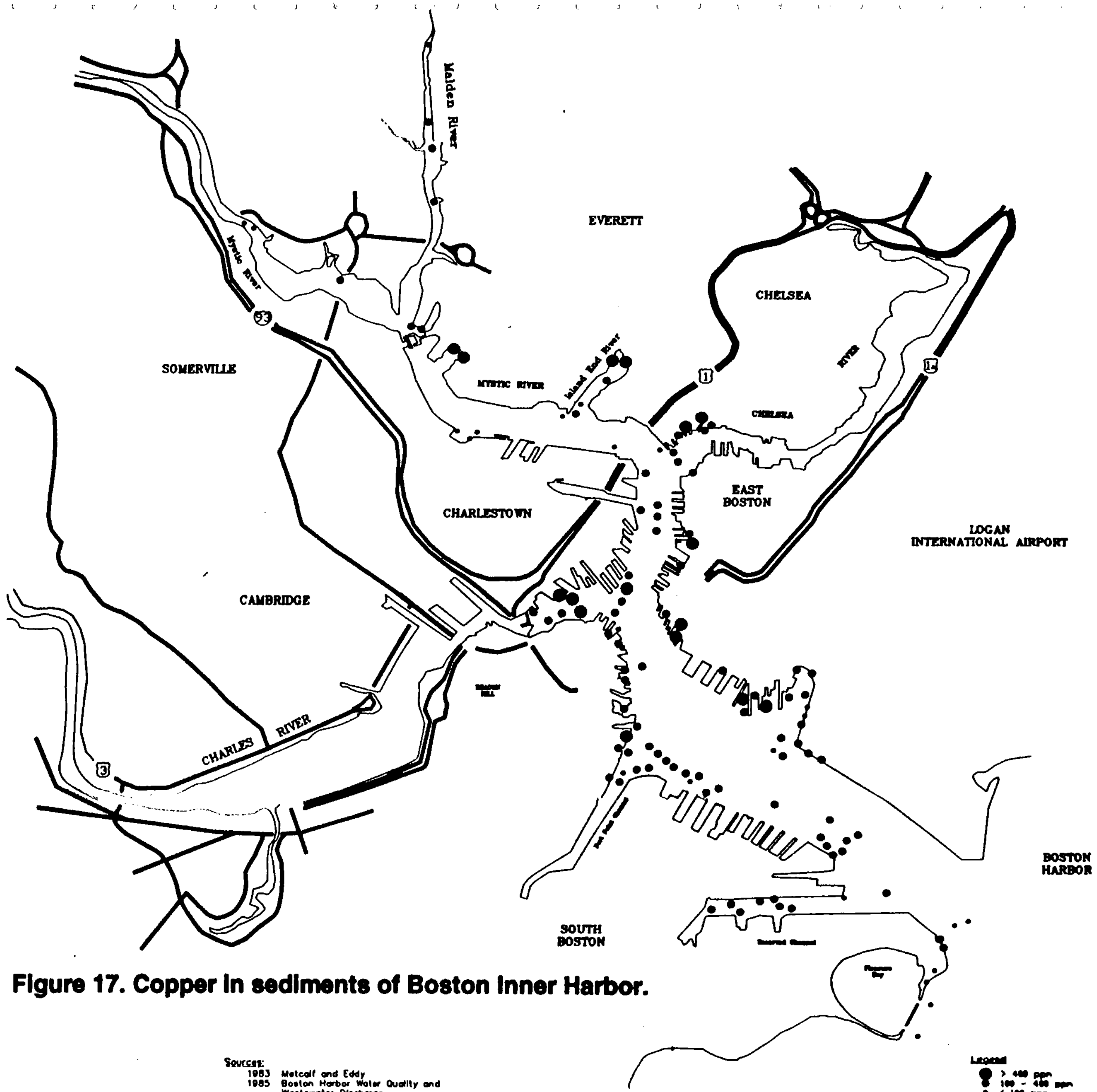


Figure 17. Copper in sediments of Boston Inner Harbor.

Sources:
1983 Metcalf and Eddy
1985 Boston Harbor Water Quality and Wastewater Discharge Data – MA DEQE DWPC
1987 Sanford Ecological Services, Inc.
1988 DEQE Historical/ Field Investigation Report (Wehran Engineering)

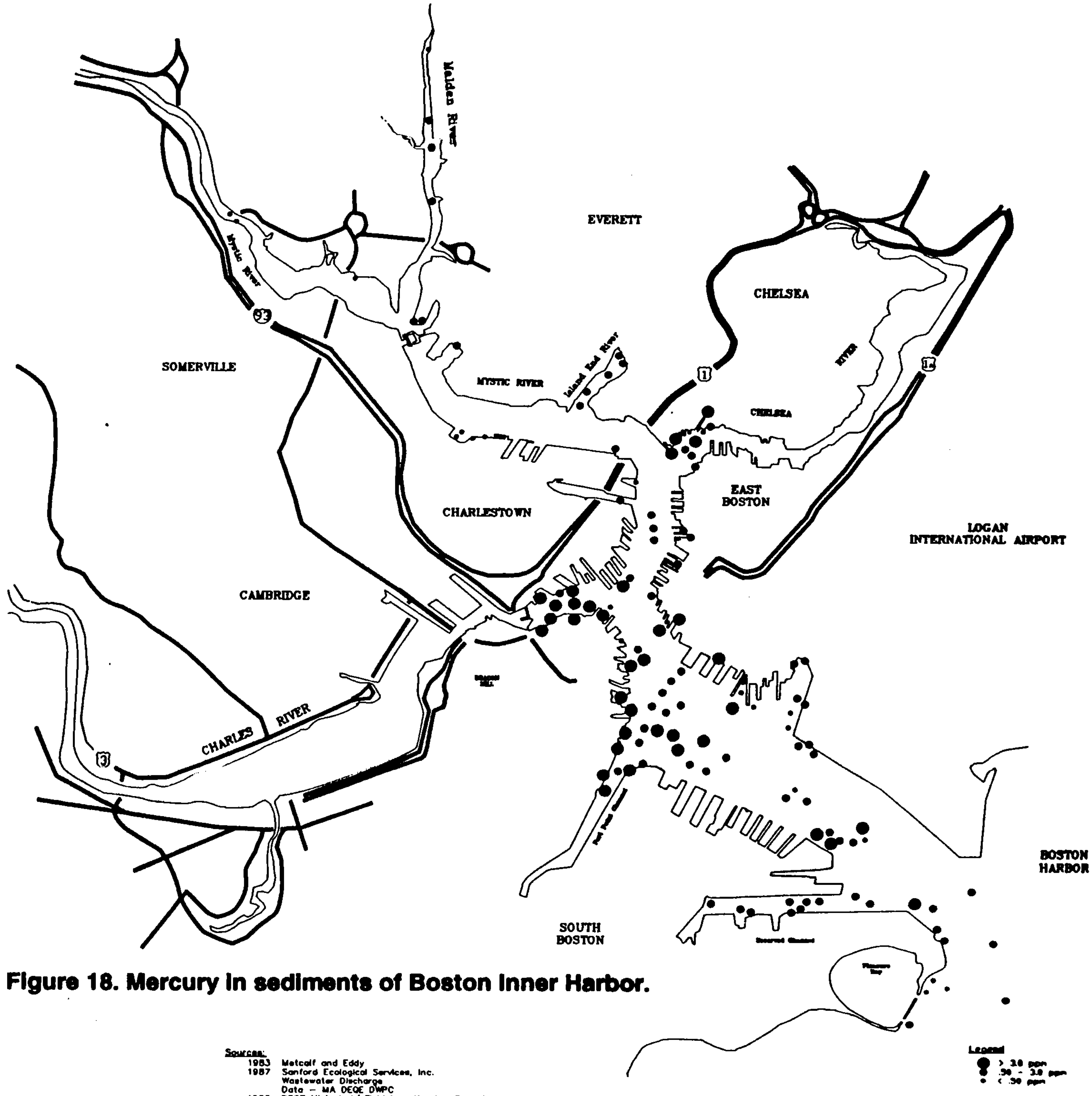


Figure 18. Mercury in sediments of Boston Inner Harbor.

Sources:
1983 Metcalf and Eddy
1987 Sanford Ecological Services, Inc.
Wastewater Discharge
Data – MA DEQE DWPC
1988 DEQE Historical/ Field Investigation Report
(Wehran Engineering)

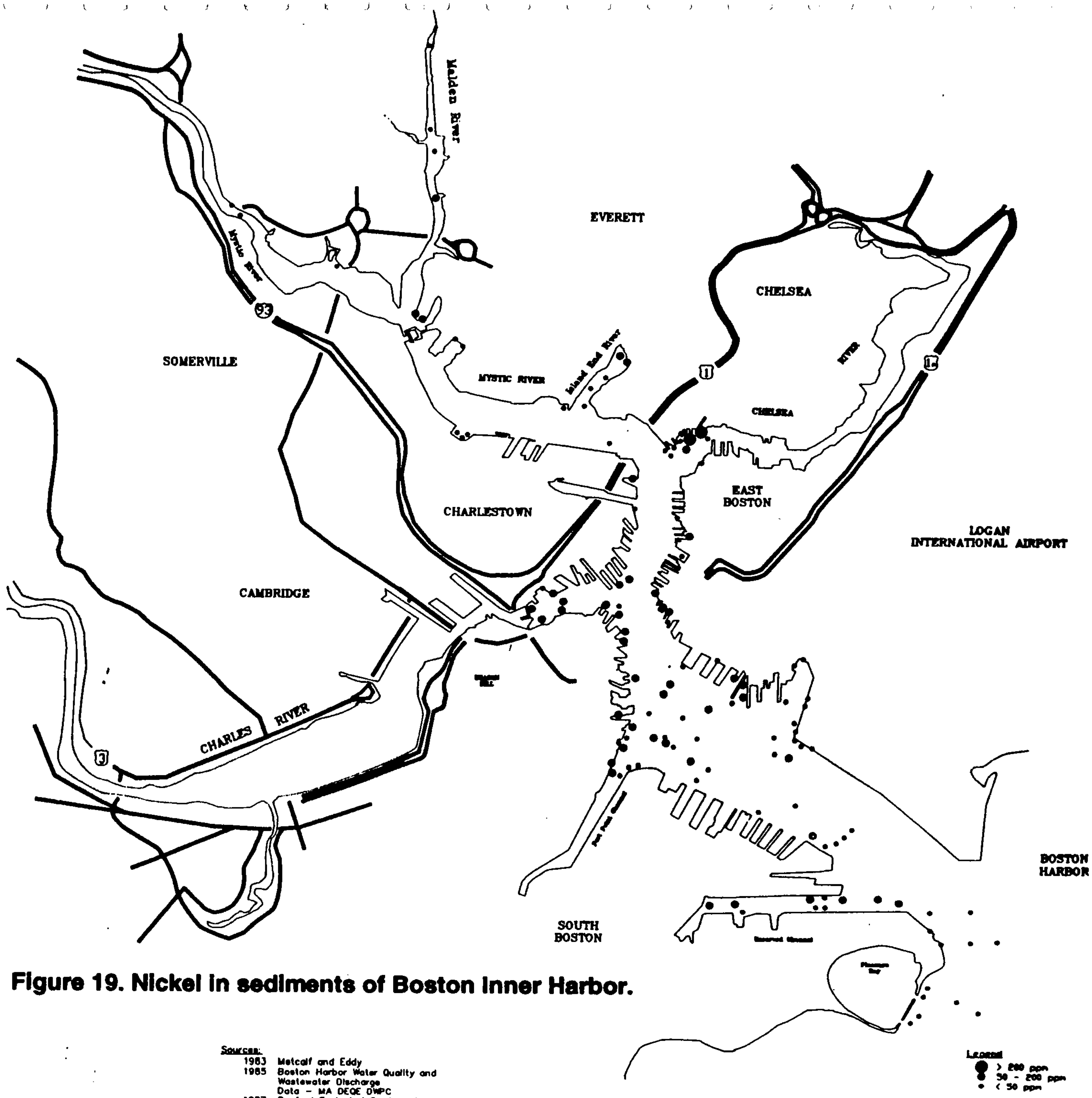


Figure 19. Nickel in sediments of Boston Inner Harbor.

Sources:
1983 Metcalf and Eddy
1985 Boston Harbor Water Quality and Wastewater Discharge Data – MA DEQE DWPC
1987 Sanford Ecological Services, Inc.
1988 DEQE Historical/ Field Investigation Report (Wehran Engineering)

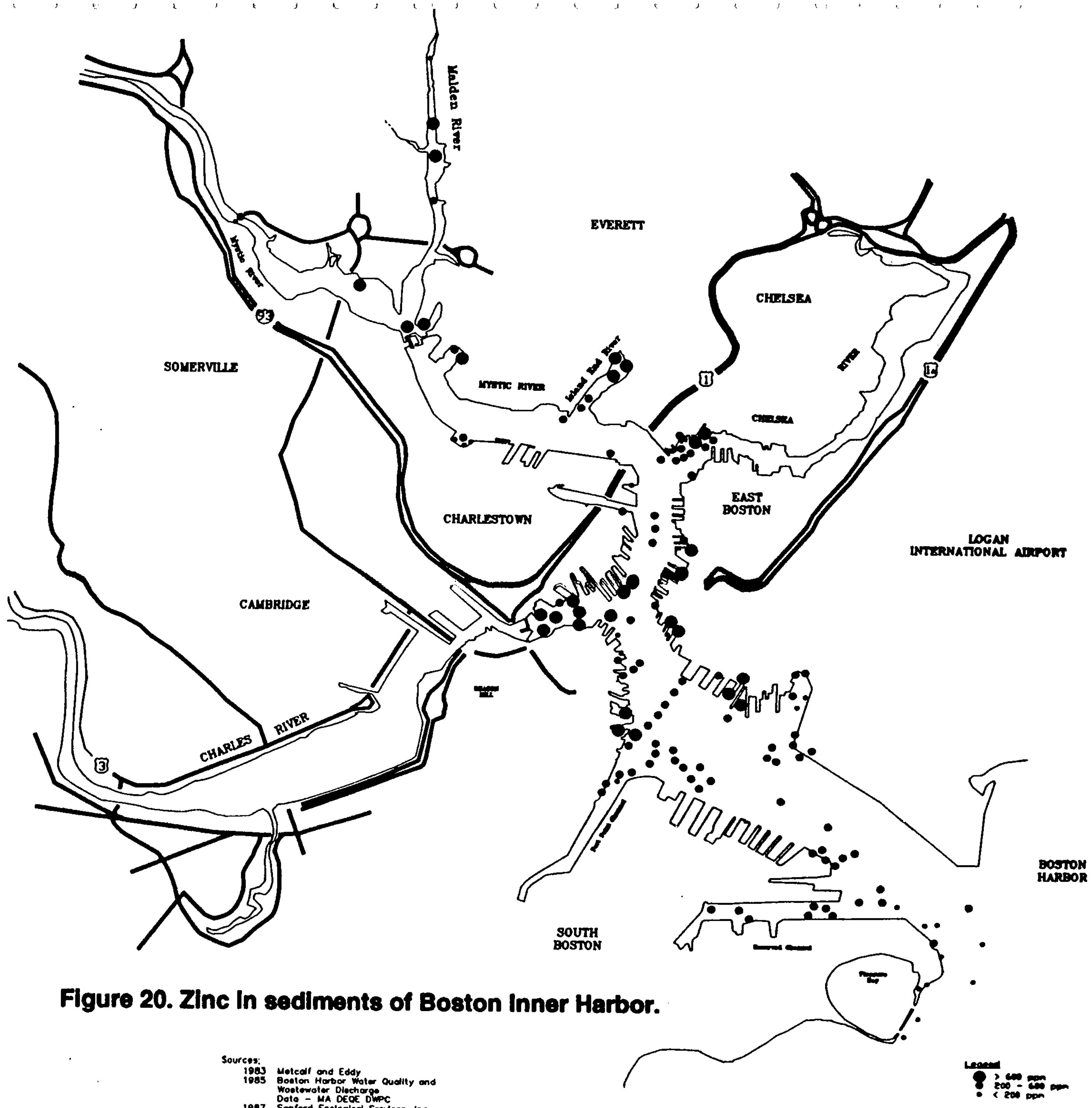


Figure 20. Zinc in sediments of Boston Inner Harbor.

Sources:
1983 Metcalf and Eddy
1985 Boston Harbor Water Quality and Wastewater Discharge Data – MA DEQE DWPC
1987 Sanford Ecological Services, Inc.
1988 DEQE Historical/ Field Investigation Report (Wehran Engineering)

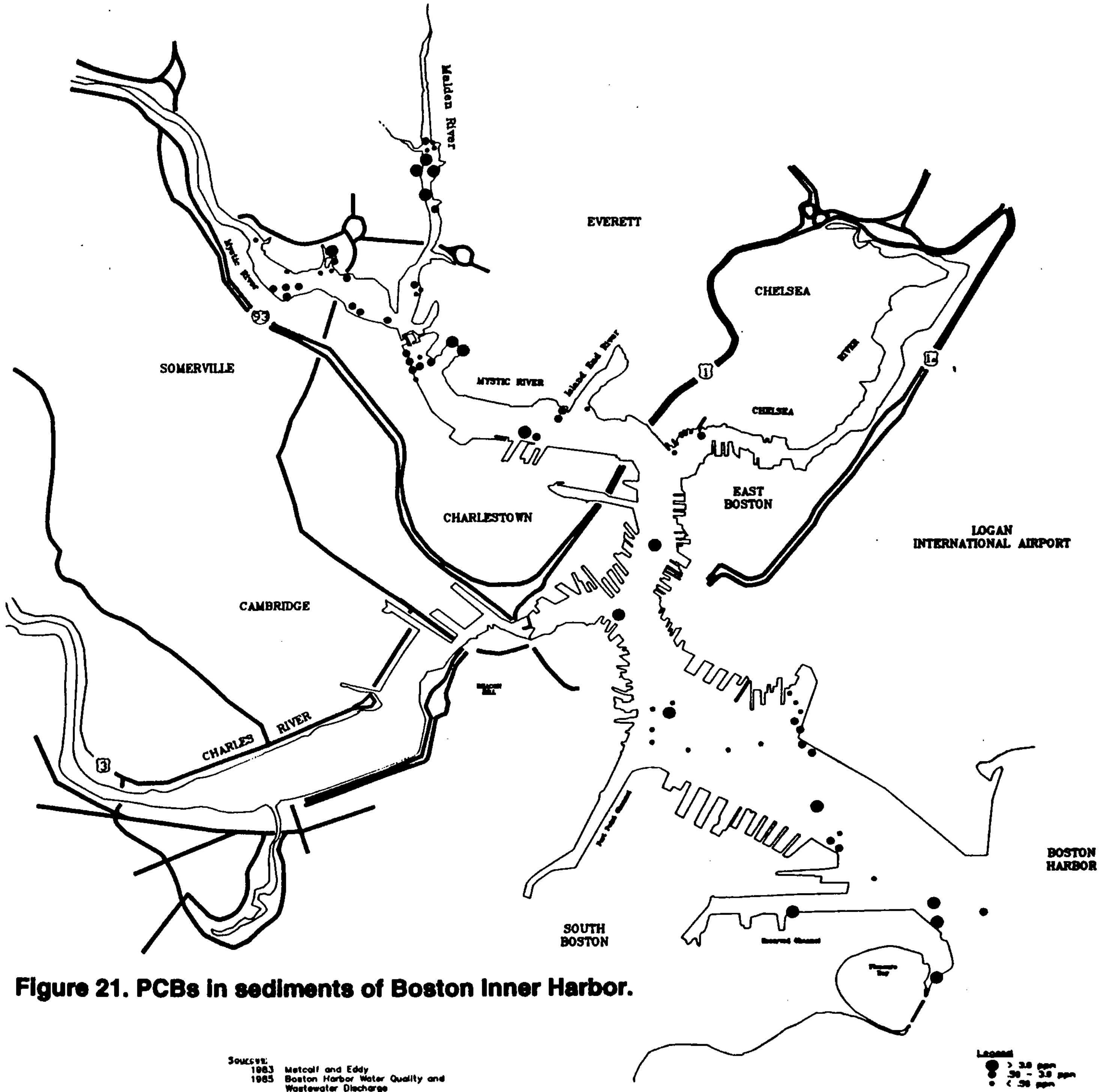


Figure 21. PCBs in sediments of Boston Inner Harbor.

Sources:
1983 Metcalf and Eddy
1985 Boston Harbor Water Quality and Wastewater Discharge Data - MA DEQE DWPC
1986 Wehran Engineering

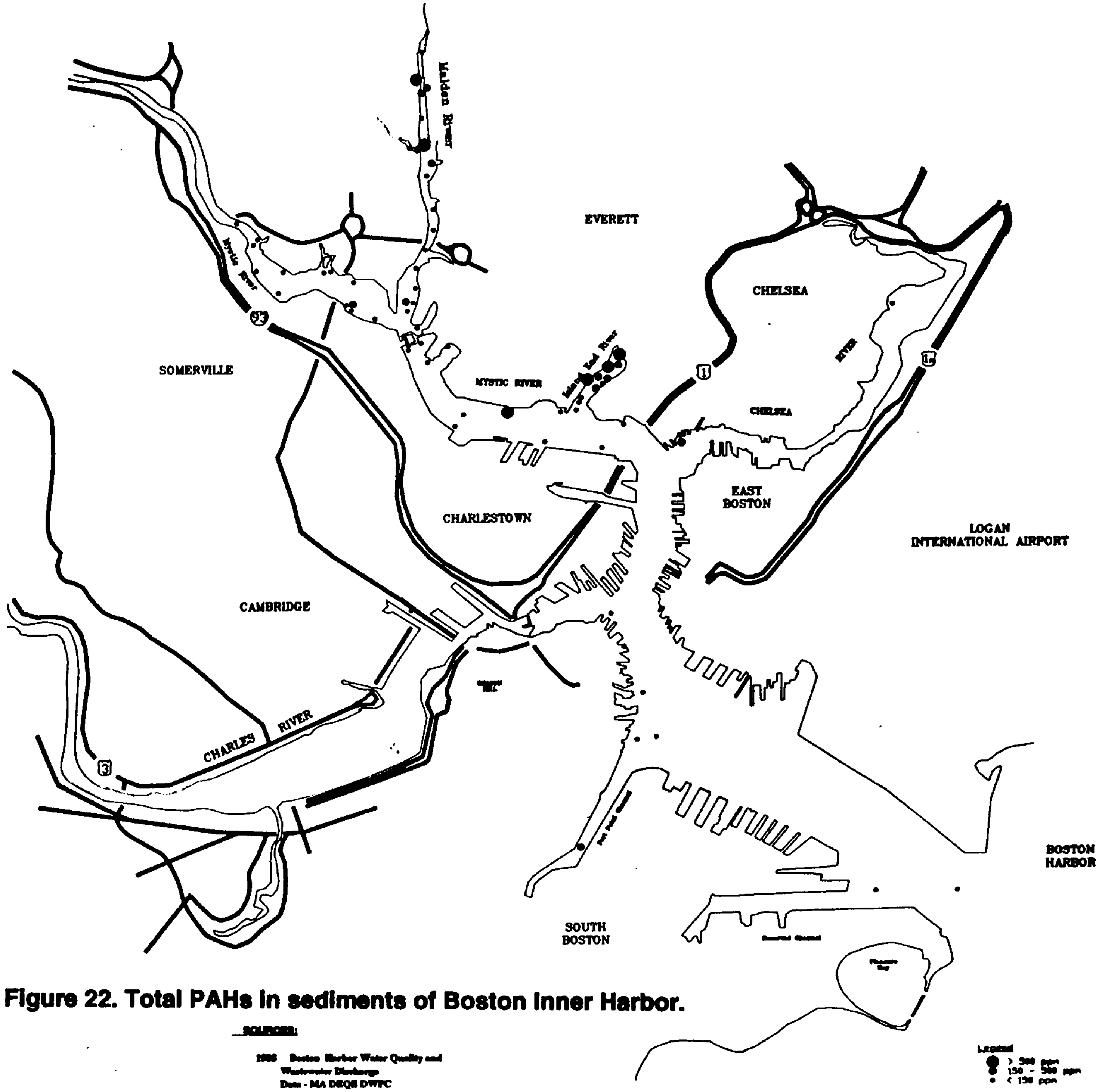


Figure 22. Total PAHs in sediments of Boston Inner Harbor.

SOURCES:

1988 Boston Harbor Water Quality and Wastewater Discharge Data - MA DEQE DWPC
1984 Wehran Engineering
1986 M.P. Shiaris
1987 Gradient Corporation
1988 DEQE Historical/Field Investigation Report

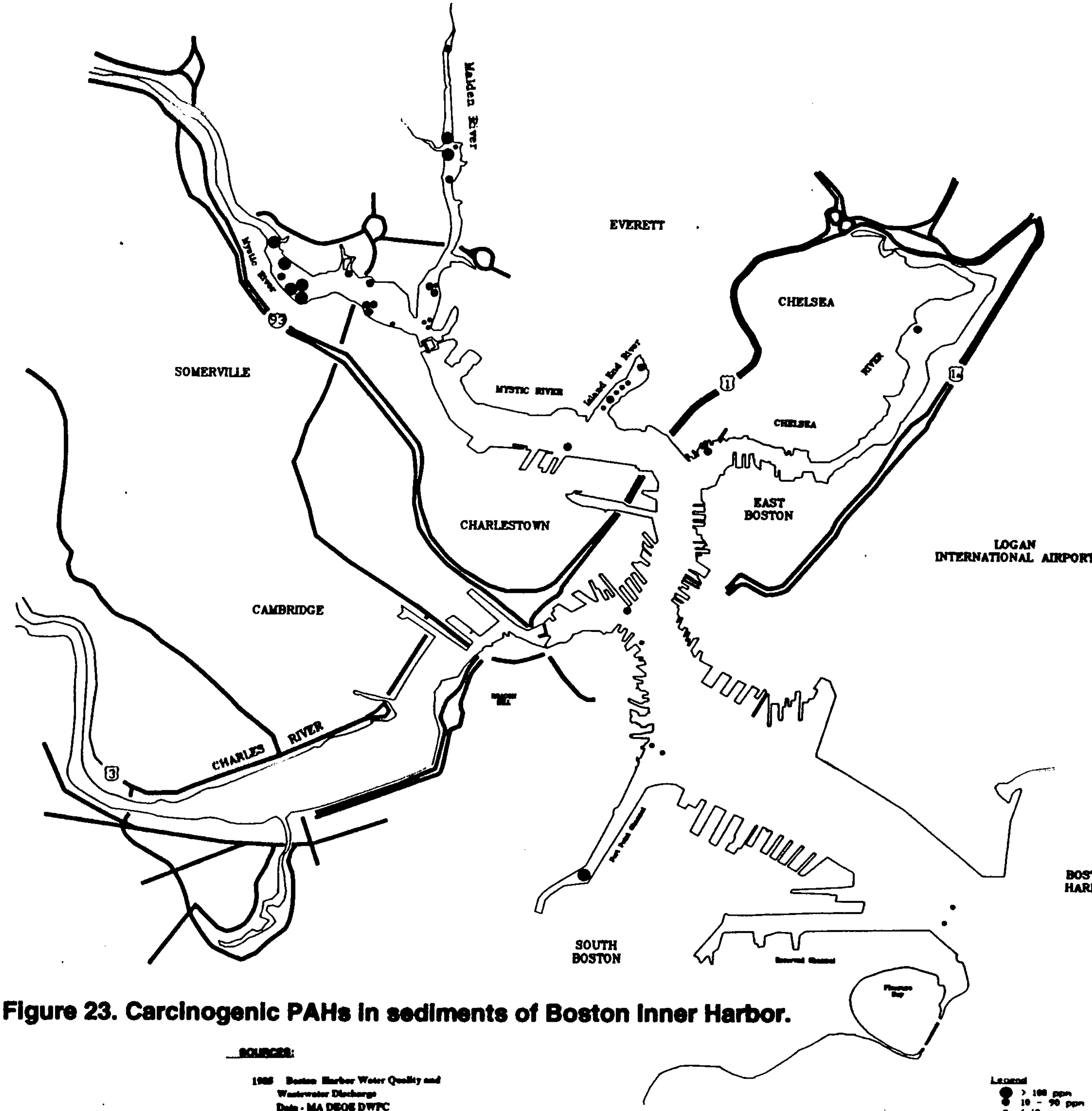


Figure 23. Carcinogenic PAHs in sediments of Boston Inner Harbor.

SOURCES:

1985 Boston Harbor Water Quality and Wastewater Discharge Data - MA DEQE DWPC
1986 Wehran Engineering
1986 M.P. Shiaris
1987 Gradient Corporation

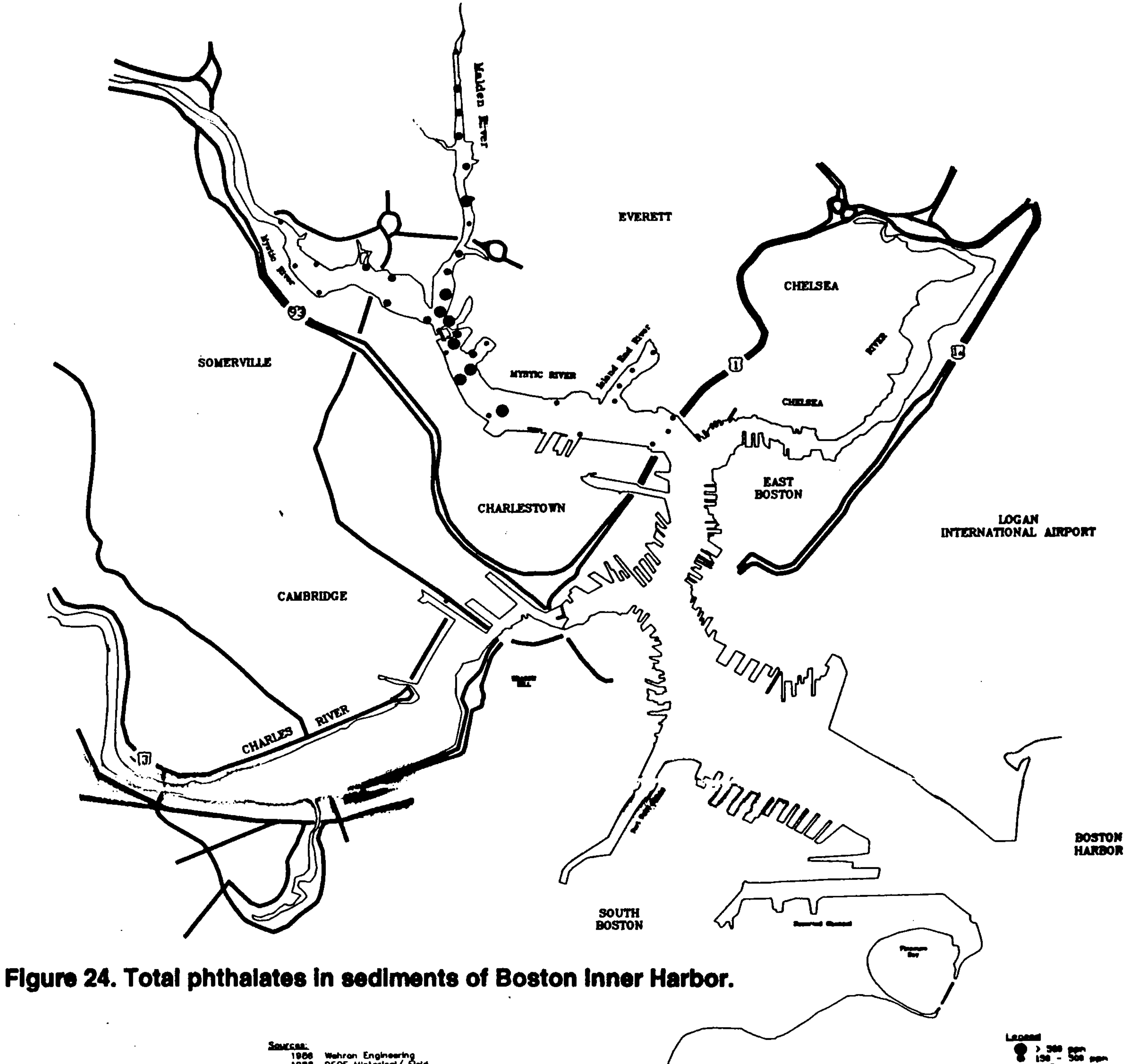


Figure 24. Total phthalates in sediments of Boston Inner Harbor.

Sources:
1986 Wehran Engineering
1988 DEQE Historical/ Field Investigation Report (Wehran Engineering)

5.8.2 Boston Harbor System

The Boston Harbor system is highly developed and includes many industries. Major tributaries are the Mystic, Charles, Neponsett, and Weymouth Rivers. The available data for this subarea are presented in Appendix B and summarized in Table 89.

Table 89. Summary of sediment samples examined in the Boston Harbor system.

	Northern Harbor	Percent of Total	Southern Harbor	Percent of Total
	#Samples		# Samples	
Total Metals	161		32	
Class II Metals	47	29.19%	10	31.25%
Class III Metals	98	60.87%	2	6.25%
Total PAH	25		8	
PAH >10 mg/kg	13	52.00%	0	0.00%
PAH >100mg/kg	6	24.00%	0	0.00%
Total PCB	37		10	
PCB >1 mg/kg	16	43.24%	4	40.00%
PCB >10 mg/kg	1	2.70%	0	0.00%

Metals

The northern Boston Harbor area (north and northwest of Long Island) exhibited higher bulk metal contamination of sediments than did the southern harbor. Over 80% of the samples collected in the northern harbor and tributaries exceeded either Category II or Category III sediment criteria used for judging disposal of dredged material. Less than 40% exceeded either of these criteria in the southern harbor. Highest concentrations tended to occur in the Inner Harbor and Mystic River drainage.

Organic Compounds

Organic compounds were found in elevated concentrations at a number of stations. PAHs were analyzed at 25 stations in the northern harbor and over 70% of these exhibited concentrations in excess of 10 mg/kg; most of these stations were located in the Inner Harbor and Mystic River system. None of the stations analyzed in the southern harbor exceeded 10 mg/kg total PAH.

PCBs were analyzed at 37 stations in the northern harbor and 10 stations in the southern harbor. The percentage of locations at which PCB concentrations exceeded 1 mg/kg was about the same (40%). Only one station, in the northern harbor, exhibited a PCB concentration in excess of 10 mg/kg.

5.8.3 The Bay

Description

The bay is bounded on the east by a line from Cape Ann in the north to Provincetown at the tip of Cape Cod. On the east it is bound by the Massachusetts Coast and a line from Winthrop to Hull. Data are particularly sparse for Cape Cod Bay and the coast south of the Weymouth River Basin. We were, however, able to obtain some data for Wellfleet Harbor from the USACE. These data are presented in Appendix B along with the data for the bay.

Metals

One hundred and one samples were collected in the bay. Of these fifty-six were classified as category III, forty-two were classified as category II and thirteen as category I. There was a concentration of contaminated sediments at the Massachusetts Bay Disposal Site as well as at the mouth of Boston Harbor. The highest concentration of each measured metal and its sample location is given in Table 90.

Table 90. The distribution of high metals concentrations in the bay subarea.

Metal	Number of Samples	Maximum Concentration (mg/kg)	Location
Ag	7	8	Mouth of Boston Harbor
An	6	3	Mouth of Boston Harbor
As	21	17	Mass Bay Disposal Site
Be	7	7	Mass Bay Disposal Site
Cd	78	4	Mass Bay Disposal Site
Co	2	22	Mouth of Boston Harbor
Cr	81	134	Mass Bay Disposal Site
Cu	81	75	Mass Bay Disposal Site
Hg	67	1	Cape Cod Bay
Mo	2	4	Mouth of Boston Harbor
Ni	79	56	Mass Bay Disposal Site
Pb	81	161	Mass Bay Disposal Site
Se	6	7	Mouth of Boston Harbor
Th	6	16	Middle of bay
Va	6	99	Mouth of Boston Harbor
Zn	79	3131	Middle of bay

Organic Compounds

Sixteen PAH samples were taken in the Bay. The highest concentration of PAH, 14 mg/kg, was found outside the mouth of Boston Harbor. This was the only sample with a concentration of PAH exceeding 10 mg/kg.

PCB and Pesticides

No pesticide samples were taken in the Bay, but 86 PCB samples were taken.

5.8.4 Data Quality and Quantity

Uncertainty

Sediment sampling programs conducted throughout the Massachusetts Bays systems have had varied objectives and have been conducted across several years. Thus, some of the data may be out of date. Also, there is considerable variability in the degree to which samples represent conditions. Much of the sampling is biased toward examining conditions thought to be contaminated or located near sources of pollutants (e.g., outfalls). Therefore, the data and statistics derived from them should not be viewed as representative of the system as a whole. Their value is in providing broad overviews of conditions in selected areas and in providing a basis for identifying potential sources of in-place sediment contamination. The identification of such areas is consistent with the generally biased nature of the sampling performed to date in the system.

A second source of variability and uncertainty in the data is the fact that we have collected the results of a large number of studies and the techniques used for sampling and analysis will differ. Such differences can result in differences in apparent contaminant concentrations from samples taken in the same area.

Finally, the level of effort among sampling areas varies greatly. Thus, there are many more samples in some areas than in others. The probability of locating in-place sediment contamination is related to some degree to the amount of effort expended. Because some harbors and near-shore areas have been sampled more extensively than others, there is a greater likelihood of identifying contamination in those areas.

6.0 CONTAMINANT LOADING AND ASSESSMENT

This section of the report provides a tabular and graphical comparison of the relative magnitude of the pollutant loadings from all sources. Implications of the data, qualifications of the data, and data gaps are also identified and discussed in this section.

6.1 Comparison of pollutant sources

The following are compared for various sources to the Massachusetts Bays: freshwater flow, total suspended solids, biochemical oxygen demand, total nitrogen, total phosphorus, oil and grease, PAHs, PCBs, cadmium, copper, chromium, lead, zinc, and mercury.

In several cases, we have used two approaches for estimating and comparing overall loadings. The main difference between the methods is in the way inland discharges are handled. One method (A) estimates loads as the sum of all discrete loadings to the drainage basins. The other (B), estimates loads as a combination of discrete sources discharging directly to coastal waters and river loads which presumably reflect inland loadings. These two approaches provide a rough basis for checking estimates.

Method A involves estimating loads by drainage area as the sum of (1) all NPDES discharge loadings to the drainage area, (2) all runoff to the drainage area, and (3) groundwater discharge to the drainage area (estimated for selected parameters for Cape Cod and Boston Harbor). Atmospheric loadings and disposal of dredged material are added to the loadings calculated from Method A to provide overall loadings to the Massachusetts Bay system.

Method B involves estimating loads by drainage area as the sum of (1) NPDES discharge loadings for coastal facilities only within each drainage area, (2) river/tributary discharge within each drainage area, (3) runoff from the coastline (within 0.5 miles of shore) except for Cape Cod for which total runoff was used because no river discharge is calculated, and (4) groundwater discharge as described above. As with Method A, atmospheric loading and dredged material disposal are added in to provide an overall estimate. Estimates for each of the components are presented in tabular form. In addition a series of bar and pie charts are used to illustrate the data.

6.1.1 Freshwater Flow

Freshwater flow to Massachusetts Bay was calculated using Method B (Table 91). Groundwater flow estimates are presented for two of the drainage areas: Boston Harbor and Cape Cod. POTWs were judged to dominate the coastal dischargers and are used to estimate freshwater input from point sources. Many of the coastal industrial NPDES permits are for cooling water systems. The total freshwater flow to Massachusetts Bay from the sources identified in Table 91 averages 462 m3/s. Much of this flow includes that of the Merrimack River (244 m3/s). The percent distribution of freshwater flow by drainage area is depicted in Figure 41 both with and without inclusion of the Merrimack River drainage area.

The Merrimack River drainage area could account for 52% of the freshwater flow to the system. Rainfall accounts for 28% if the Merrimack is included and 58% if the Merrimack is excluded from the estimate. Nonpoint sources dominate the freshwater inflow for all drainage areas except the Boston Harbor system which is dominated by the NPDES outfalls from the Deer and Nut Island POTWs. If the Merrimack River is excluded the Boston Harbor drainage area accounts for 27% of the freshwater flow to the bay.

Groundwater also appears to be important. Estimates were made for the Boston Harbor and Cape Cod drainage areas. For the latter, total groundwater inflow to Cape Cod Bay is estimated to amount to 4.1 m3/s. This discharge dominates over runoff for Cape Cod and is equivalent to one-half the riverine inputs estimated for the South Shore Drainage Area.

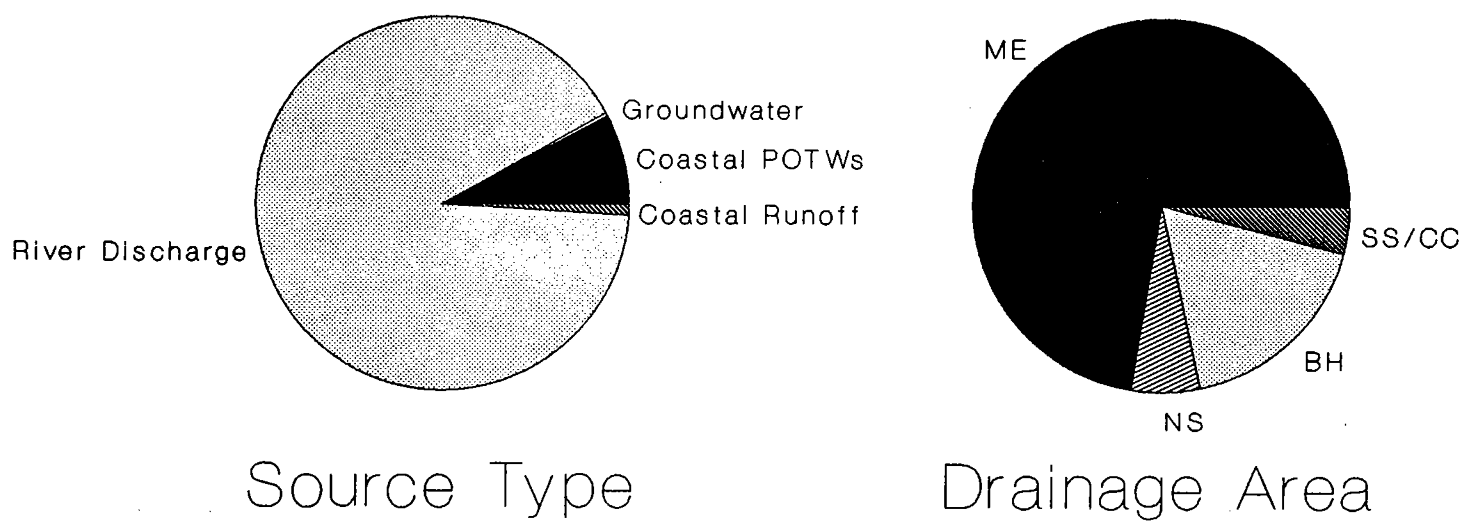
Our estimates did not include estimates of freshwater inputs from the Gulf of Maine. This source may in fact provide the greatest inputs of freshwater to the system, so this exclusion is significant.

Even for this most basic measurement, data are subject to uncertainties. Annual river flows were estimated by several methods, depending upon whether gauge measurements were available. Seasonal and year-to-year variability is also high for flow. Where seasonal variability was measured, flow tended to be high during March-May than in other months. Annual variability can also be substantial. This variability affects not only the measurements of flow but the measurements of inputs of the pollutants.

Table 91. Freshwater inflow to Massachusetts Bay (m3/s).

Freshwater Flow	**Drainage Area**						
m3/s		**North**	**Boston**	**South**	**Cape**		
Source	**Merrimack**	**Shore**	**Harbor**	**Shore**	**Cod**	**Direct**	**Totals**
Drainage Area Calculation							
Using Method A	This method was not used in the calculation of freshwater flow						
NPDES							
Runoff/CSOs							
Groundwater							
Totals =							
Drainage Area Calculation							
Using Method B							
Coastal POTWs		5.37E+00	2.01E+01	4.37E-01			2.59E+01
Coastal Runoff/CSOs (1)	3.65E-01	2.59E-01	2.22E+00	1.93E-01	3.60E-01		3.04E+00
River Discharge	2.44E+02	1.41E+01	3.60E+01	8.48E+00			3.02E+02
Groundwater			9.80E-01		4.06E+00		9.80E-01
Totals =	2.44E+02	1.97E+01	5.93E+01	9.11E+00	4.42E+00	0.00E+00	3.32E+02
Direct Sources to Mass Bays							
Atmosphere						1.29E+02	0.00E+00
Dredge Material							0.00E+00
Totals with Approach A							
Totals with Approach B	2.44E+02	1.97E+01	5.93E+01	9.11E+00	4.42E+00	1.29E+02	
TOTAL FOR MASS BAYS WITH APPROACH A =					Not calculated		
TOTAL FOR MASS BAYS WITH APPROACH B =					4.66E+02		
1. CSO/Runoff for Boston Harbor is taken from Menzie-Cura 1991 and includes CH2M Hill and NURP							

Figure 25. Contribution of various sources to freshwater inflow.



6.1.2 Total Suspended Solids

Loadings of total suspended solids are presented in Table 92 and Figures 26 and 27. Methods A and B yielded loadings estimates of 555,000 mt/yr and 299,000 mt/yr respectively. Atmospheric loadings are not included.

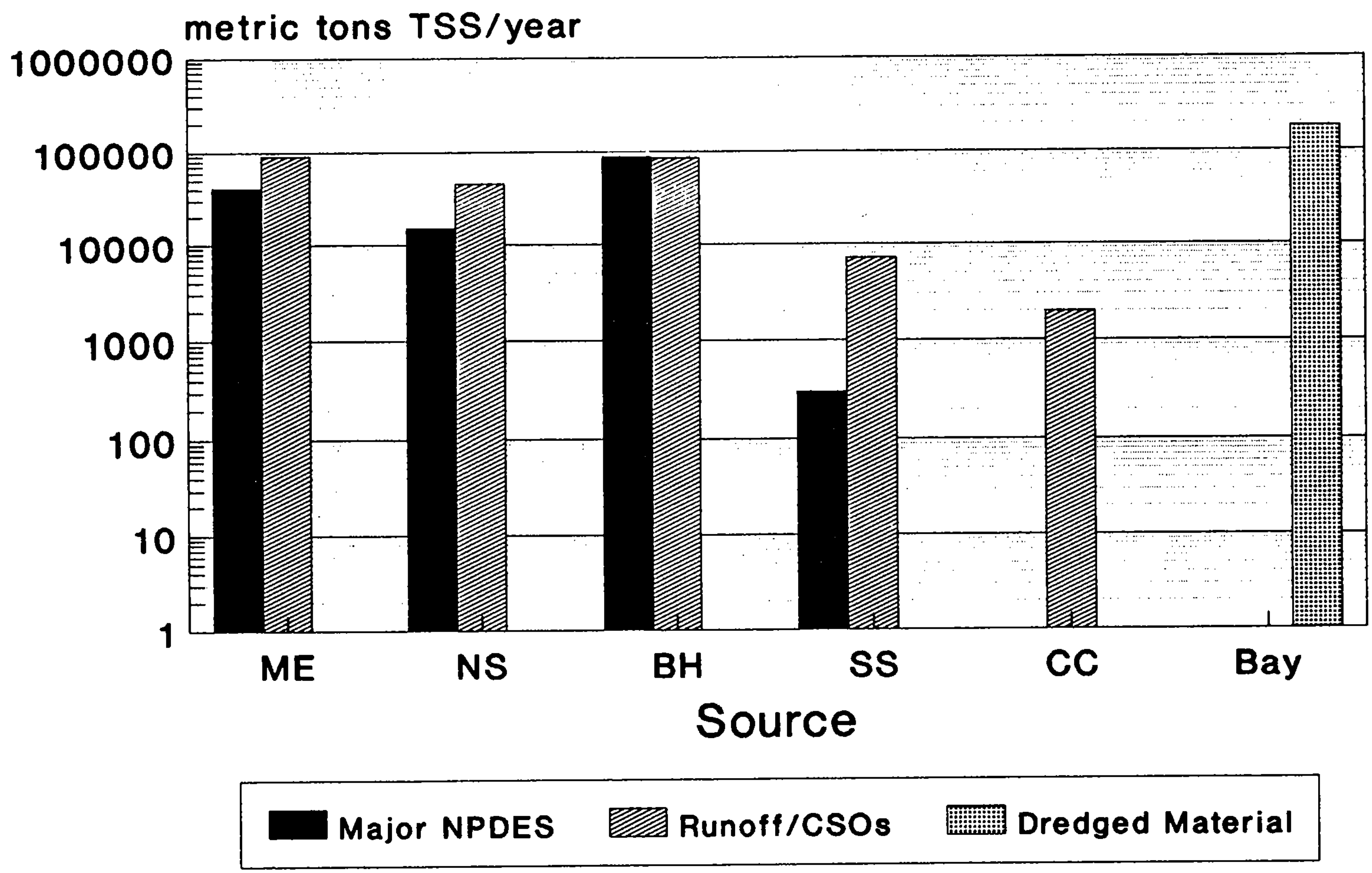
The disposal of dredged material was a major contributor to loadings and accounted for 31% of the Method A estimate and 60% of the Method B estimate. These solids are added to one site within the system and would not be expected to affect the system in the same way as loadings from discharges and runoff. NPDES discharges accounted for 27% of the Method A estimate with Boston Harbor discharges comprising 60% of this source of loadings.

Loadings delivered to the system via runoff amounted to 41% of the Method A estimate. Loadings associated with rivers accounted for 26% of the Method B estimate. Because suspended solids are expected to settle out to some extent within the drainage basins, the nonpoint source loadings provided in Method B (primarily direct river discharge) may be a better estimate than those in Method A.

Table 92. Suspended sediment load to Massachusetts Bay by source (kg/yr).

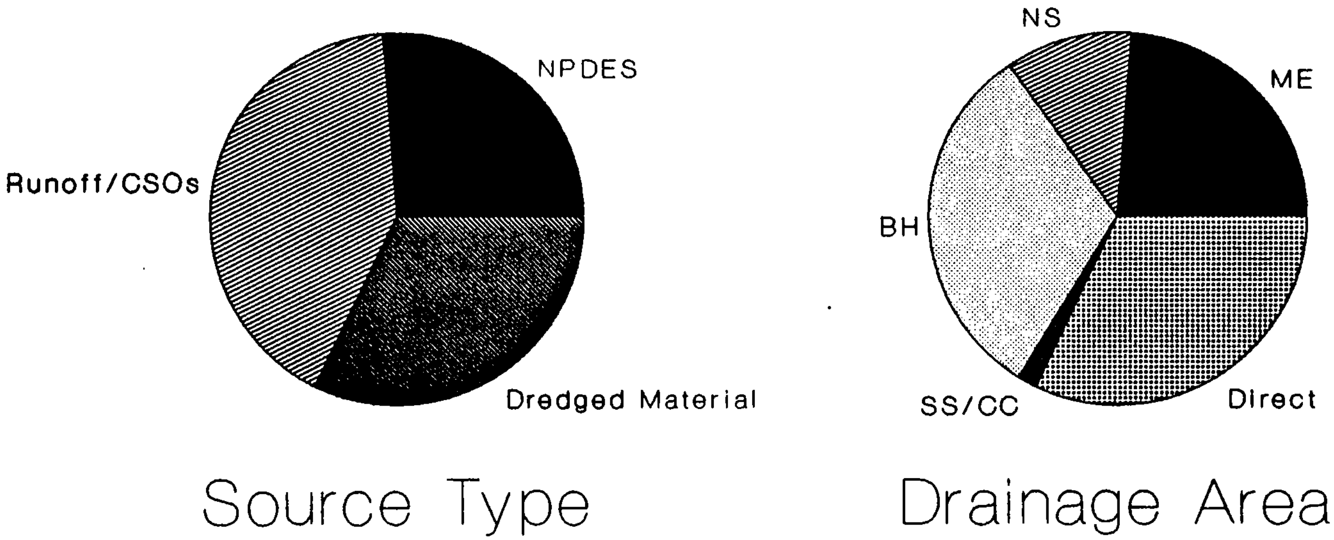
Suspended Solids kg/yr Source	Drainage Area: Merrimack	North Shore	Boston Harbor	South Shore	Cape Cod	Direct	Totals
Drainage Area Calculation Using Method A							
NPDES	4.12E+07	1.50E+07	8.81E+07	2.99E+05			1.45E+08
Runoff/CSOs	9.09E+07	4.59E+07	8.64E+07	7.09E+06	1.96E+06		2.30E+08
Groundwater							0.00E+00
Totals =	1.32E+08	6.09E+07	1.75E+08	7.39E+06	1.96E+06	0.00E+00	3.75E+08
Drainage Area Calculation Using Method B							
Coastal NPDES		1.54E+07	2.30E+07	2.50E+05	6.60E+03		3.87E+07
Coastal Runoff/CSOs	2.04E+05	1.20E+06	1.55E+06	5.68E+05	1.18E+06		3.52E+06
River Discharge	5.83E+07	3.74E+06	1.27E+07	2.13E+06			7.69E+07
Groundwater							0.00E+00
Totals =	5.85E+07	2.03E+07	3.72E+07	2.95E+06	1.18E+06	0.00E+00	1.19E+08
Direct Sources to Mass Bays							
Atmosphere							0.00E+00
Dredged Material						1.78E+08	1.78E+08
Totals with Approach A	1.32E+08	6.09E+07	1.75E+08	7.39E+06	1.96E+06	1.78E+08	
Totals with Approach B	5.85E+07	2.03E+07	3.72E+07	2.95E+06	1.18E+06	1.78E+08	
TOTAL FOR MASS BAYS WITH APPROACH A =					5.55E+08		
TOTAL FOR MASS BAYS WITH APPROACH B =					2.99E+08		

Figure 26. Suspended sediment load to Massachusetts Bays by source (mt/yr)



No estimates were made of atmospheric loading

Figure 27. Relative contributions to suspended sediment load.



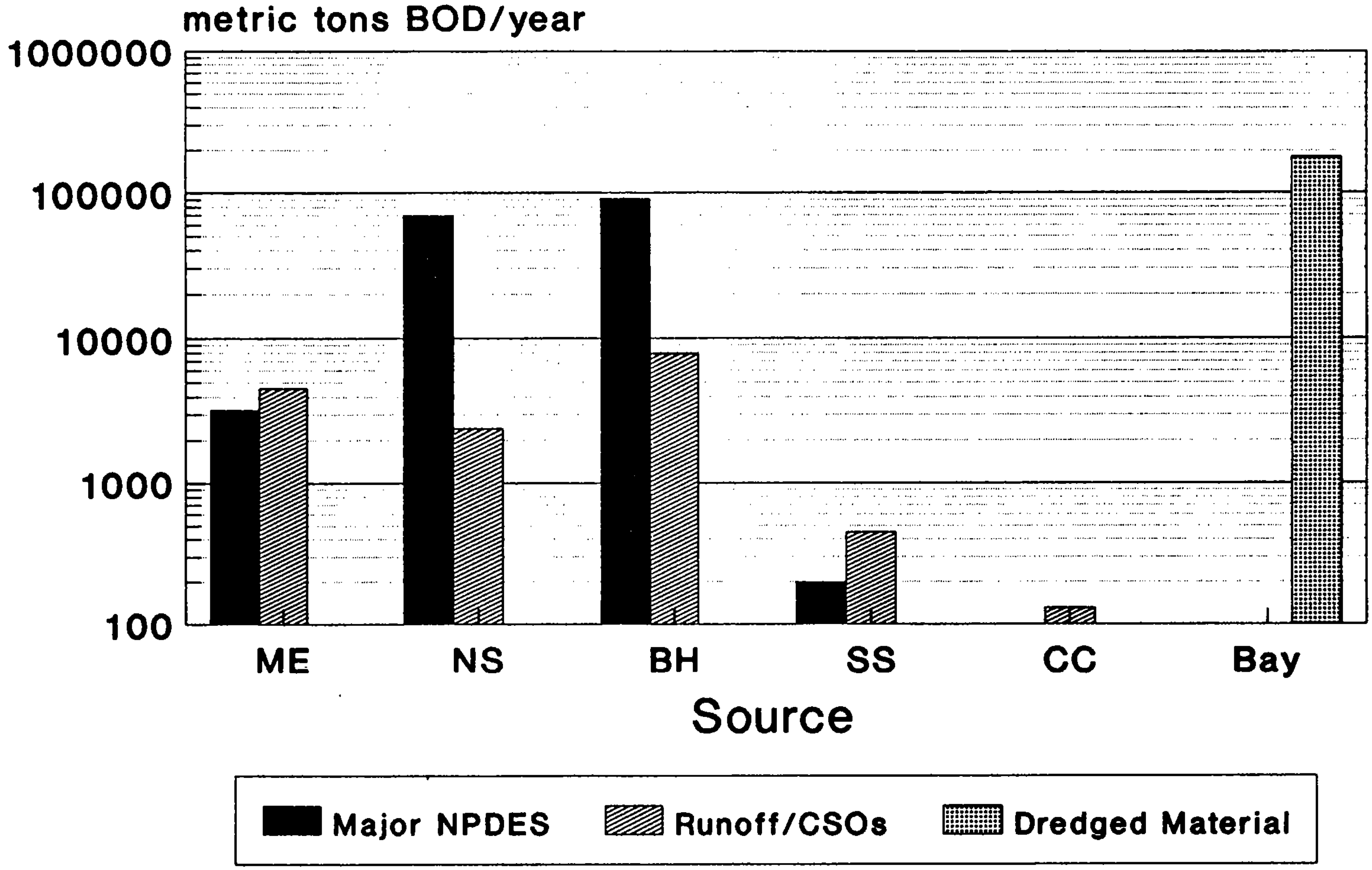
6.1.3 Biochemical Oxygen Demand (BOD)

Loadings of BOD to the Massachusetts Bay system are summarized in Table 93 and Figures 28 and 29. The estimates do not include inputs from the atmosphere, dredged material disposal or groundwater. Methods A and B gave almost identical total loadings of BOD to Massachusetts Bay at approximately 180,000 mt/yr. Most of this (90%) was due to NPDES dischargers with approximately 10% due to runoff or riverine inflow. The Boston Harbor NPDES outfalls accounted for approximately 56% of the coastal NPDES BOD inputs to the bay.

Table 93. BOD load to Massachusetts Bay by source (kg/yr).

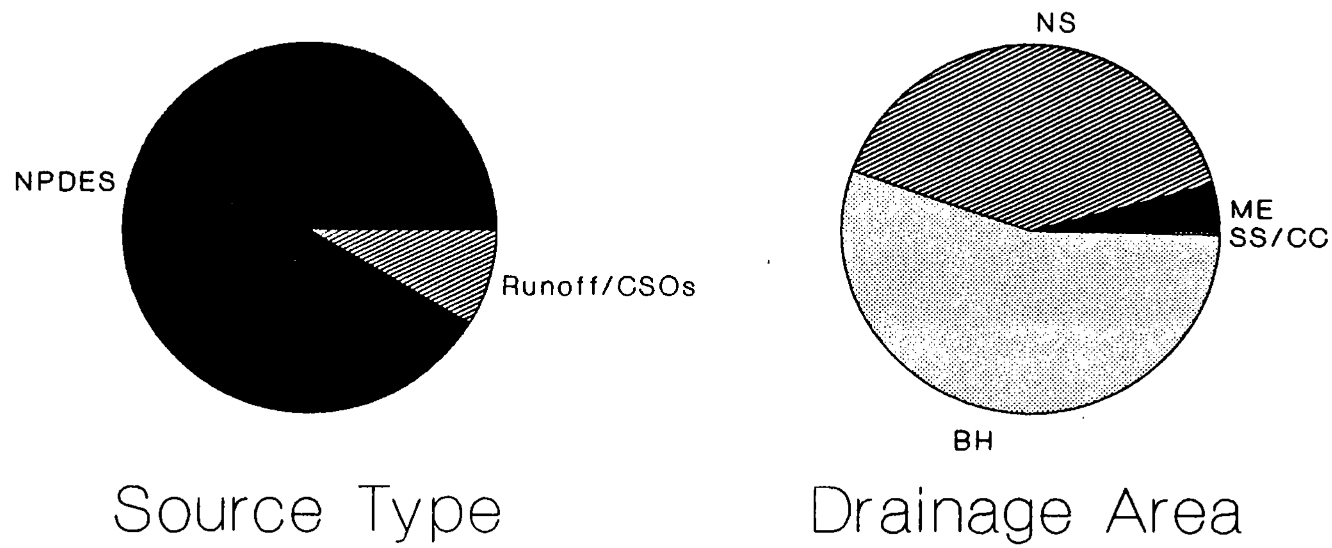
Biochemical Oxygen Demand	Drainage Area						
kg/yr		North	Boston	South	Cape		
Source	Merrimack	Shore	Harbor	Shore	Cod	Direct	Totals
Drainage Area Calculation							
Using Method A							
NPDES	3.24E+06	6.98E+07	9.10E+07	1.98E+05			1.64E+08
Runoff/CSOs	4.55E+06	2.40E+06	7.86E+06	4.50E+05	1.30E+05		1.53E+07
Groundwater	No estimate was made						0.00E+00
Totals =	7.79E+06	7.22E+07	9.89E+07	6.48E+05	1.30E+05	0.00E+00	1.79E+08
Drainage Area Calculation							
Using Method B							
Coastal NPDES		6.98E+07	9.10E+07	1.40E+05			1.61E+08
Coastal Runoff/CSOs	1.24E+04	1.32E+05	2.55E+05	3.60E+04	1.30E+05		4.35E+05
River Discharge	1.24E+07	1.27E+06	3.41E+06	8.02E+05			1.79E+07
Groundwater	No estimate was made						0.00E+00
Totals =	1.24E+07	7.12E+07	9.47E+07	9.78E+05	1.30E+05	0.00E+00	1.79E+08
Direct Sources to Mass Bays							
Atmosphere	No estimate was made						0.00E+00
Dredged Material	No estimate was made						0.00E+00
Totals with Approach A	7.79E+06	7.22E+07	9.89E+07	6.48E+05	1.30E+05	0.00E+00	
Totals with Approach B	1.24E+07	7.12E+07	9.47E+07	9.78E+05	1.30E+05	0.00E+00	
TOTAL FOR MASS BAYS WITH APPROACH A =					1.80E+08		
TOTAL FOR MASS BAYS WITH APPROACH B =					1.79E+08		

Figure 28. BOD load to Mass Bay by source (mt/yr)



No estimates were made of atmospheric loading

Figure 29 Relative contribution to BOD load.



6.1.4 Total Nitrogen

Loadings of nitrogen to Massachusetts Bay are summarized in Table 94 and Figures 30 and 31. Estimates were developed for all sources although groundwater estimates were made for Boston Harbor and Cape Cod only. Methods A and B yielded comparable results with estimates of 28,000 mt/yr and 36,000 mt/yr.

Much of the nitrogen load is due to NPDES discharges which account for 66% of the Method A estimate and 43% of the Method B estimate. Our flow-based low and high measurements of nitrogen inputs were very similar, about 18,000 mt/yr.

For Method A, runoff (11%) and atmospheric deposition (16%) were other important sources, using our high estimates. Estimates of nitrogen input from the atmosphere ranged from 1,600 to 4,500 mt/yr, and no range in measurements of runoff was calculated. For Method B, river discharges accounted for 37% of the estimate.

Groundwater discharge appears to be an important local near-shore source of nitrogen for Cape Cod. Loadings via groundwater from the Cape are estimated at 224-322 mt/yr as compared to 31 mt/yr due to runoff from the Cape. Groundwater discharge of nitrogen into Boston Harbor is about an order of magnitude lower than that for the Cape. This difference reflects the smaller drainage area of the Boston Harbor system for direct recharge to the harbor.

Table 94. Nitrogen load to Massachusetts Bay by source (kg/yr).

Nitrogen kg/yr Source	Drainage Area: Merrimack	North Shore	Boston Harbor	South Shore	Cape Cod	Direct	Totals
Drainage Area Calculation Using Method A							
NPDES	2.17E+06	4.09E+06	1.21E+07	8.45E+04			1.85E+07
Runoff/CSOs	1.07E+06	5.68E+05	1.34E+06	1.04E+05	3.12E+04		3.11E+06
Groundwater	NA	NA	3.14E+04	NA	3.22E+05		3.53E+05
Totals =	3.24E+06	4.66E+06	1.35E+07	1.89E+05	3.53E+05	0.00E+00	2.20E+07
Drainage Area Calculation Using Method B							
Coastal NPDES		4.05E+06	1.14E+07	7.90E+04			1.55E+07
Coastal Runoff/CSOs	2.25E+03	1.59E+04	2.69E+04	8.27E+03	3.12E+04		8.45E+04
River Discharge	1.11E+07	6.32E+05	1.76E+06	3.45E+05			1.38E+07
Groundwater	NA	NA	1.57E+04	NA	3.22E+05		3.38E+05
Totals =	1.11E+07	4.70E+06	1.32E+07	4.32E+05	3.53E+05	0.00E+00	2.98E+07
Direct Sources to Mass Bays							
Atmosphere						4.48E+06	4.48E+06
Dredge Material						1.25E+06	1.25E+06
Totals with Approach A	3.24E+06	4.66E+06	1.35E+07	1.89E+05	3.53E+05	5.73E+06	
Totals with Approach B	1.11E+07	4.70E+06	1.32E+07	4.32E+05	3.53E+05	5.73E+06	
TOTAL FOR MASS BAYS WITH APPROACH A =					2.77E+07		
TOTAL FOR MASS BAYS WITH APPROACH B =					3.55E+07		

Figure 30. Nitrogen load to Mass Bay by source (mt/yr)

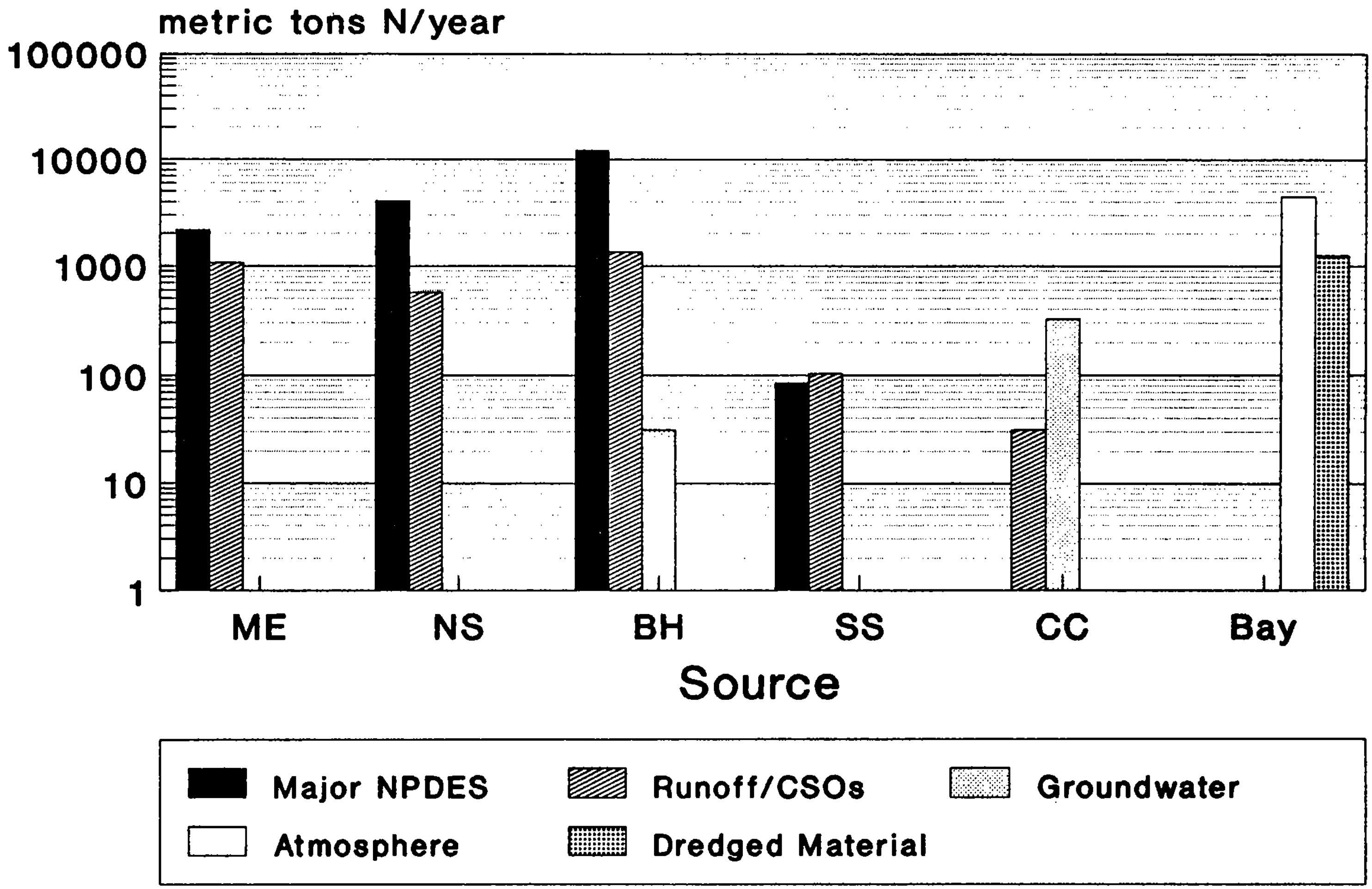
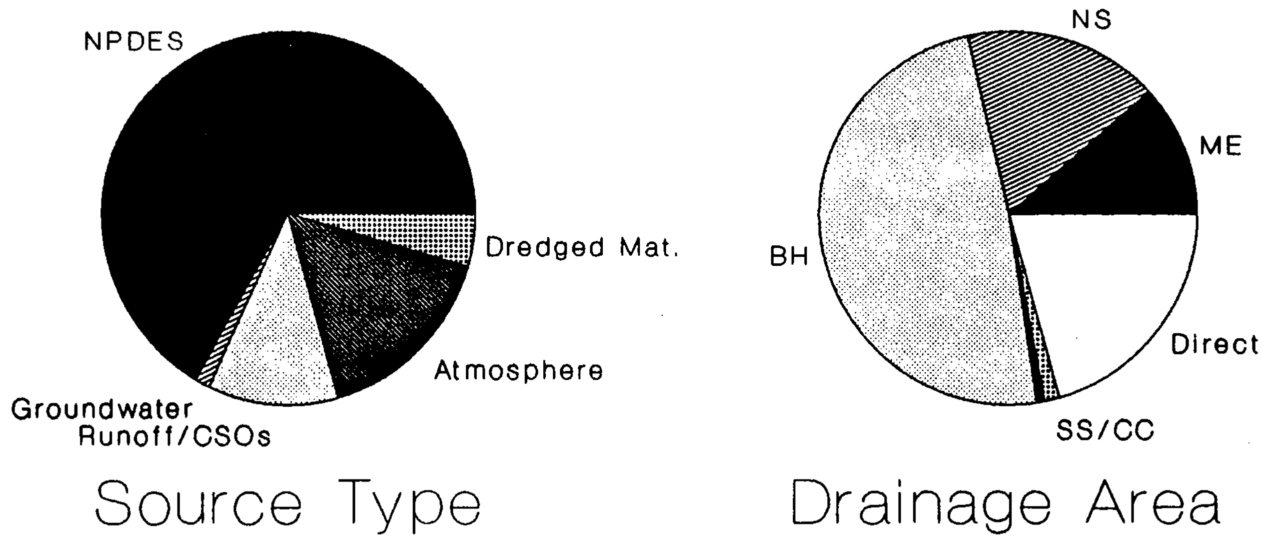


Figure 31. Relative contributions nitrogen load.



6.1.5 Total Phosphorus

Loadings of phosphorus to Massachusetts Bay are summarized in Table 95 and Figures 32 and 33. No estimates have been developed for dredged material. Total loadings are estimated to be 3,880 metric tons using Method A and 4,100 metric tons using Method B.

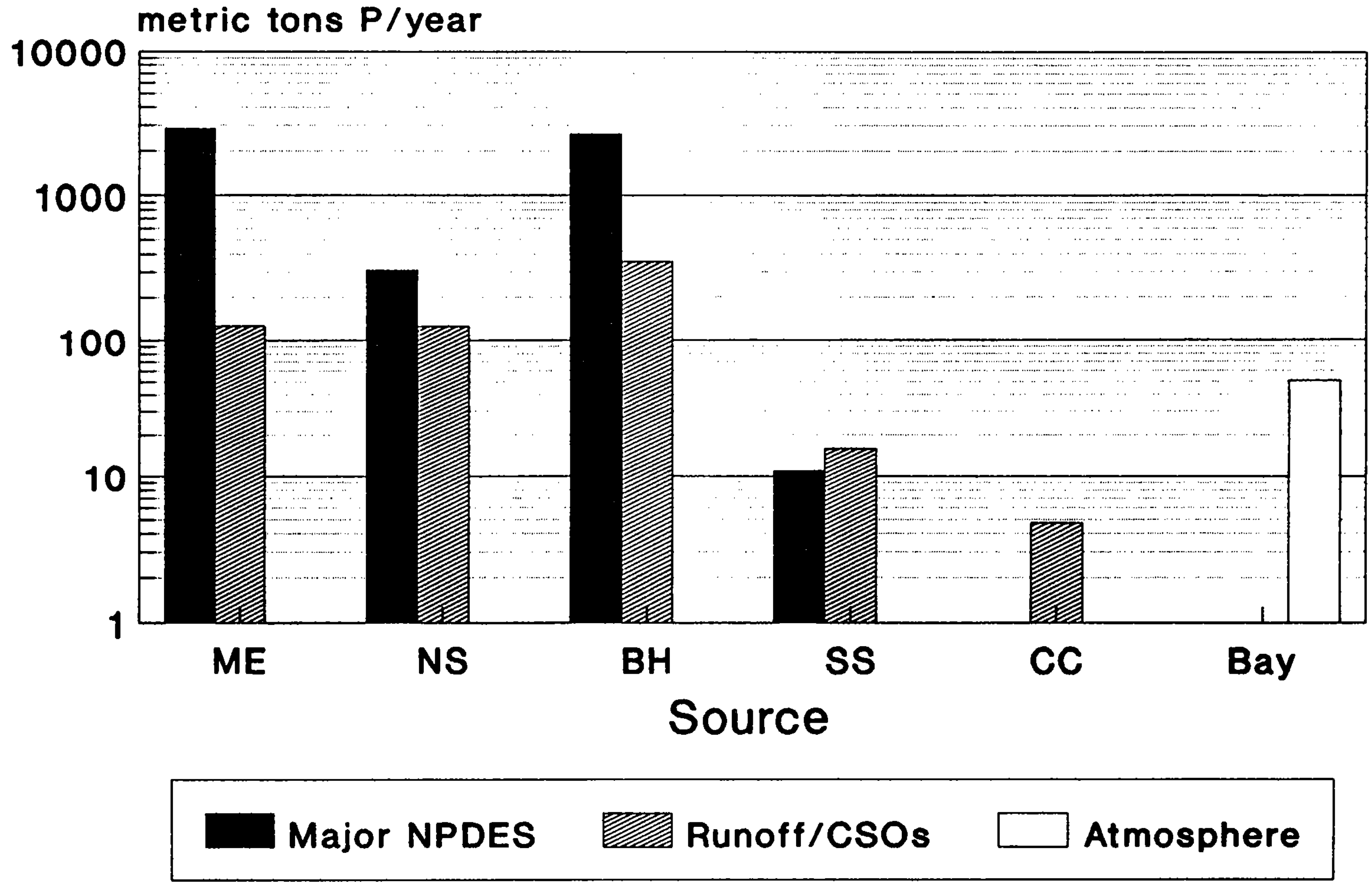
NPDES discharges account for 82% of the load using Method A and 71% using Method B. Our low and high measurements of these inputs were essentially equal, 3,100-3,200 mt/yr. The Boston Harbor drainage area accounts for most of the NPDES load (81% of the Method A estimate for this source). River discharge accounts for 27% of the Method B estimate.

Atmospheric deposition does not appear to account for significant loads of phosphorus.

Table 95. Phosphorus load to Massachusetts Bay by source (kg/yr).

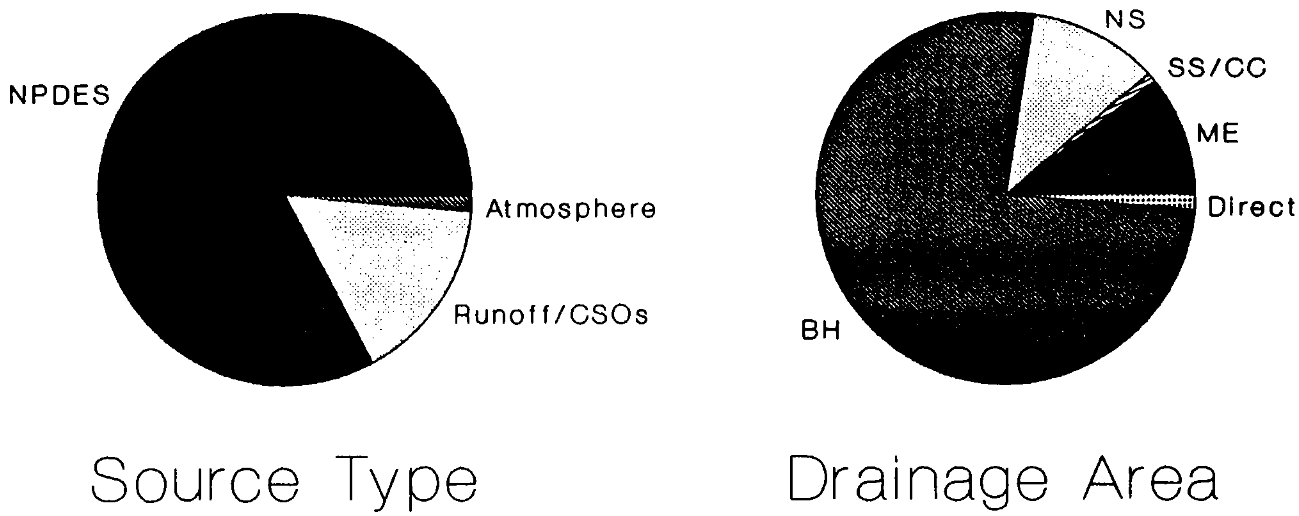
Phosphorus kg/yr Source	Drainage Area: Merrimack	North Shore	Boston Harbor	South Shore	Cape Cod	Direct	Totals
Drainage Area Calculation Using Method A							
NPDES	2.82E+05	3.10E+05	2.60E+06	1.10E+04			3.20E+06
Runoff/CSOs (1)	1.27E+05	1.25E+05	3.52E+05	1.58E+04	4.69E+03		6.20E+05
Groundwater	NA	NA	NA	NA	NA		0.00E+00
Totals =	4.09E+05	4.35E+05	2.95E+06	2.68E+04	4.69E+03	0.00E+00	3.82E+06
Drainage Area Calculation Using Method B							
Coastal NPDES		3.10E+05	2.60E+06	1.10E+04			2.92E+06
Coastal Runoff/CSOs (1)	3.82E+02	3.74E+03	7.05E+03	1.26E+03	2.82E+03		1.24E+04
River Discharge	1.08E+06	1.08E+04	5.79E+03	8.34E+02			1.10E+06
Groundwater	NA	NA	NA	NA	NA		0.00E+00
Totals =	1.08E+06	3.25E+05	2.61E+06	1.31E+04	2.82E+03	0.00E+00	4.03E+06
Direct Sources to Mass Bays							
Atmosphere						5.10E+04	5.10E+04
Dredge Material (no estimates were developed)							0.00E+00
Totals with Approach A	4.09E+05	4.35E+05	2.95E+06	2.68E+04	4.69E+03	5.10E+04	
Totals with Approach B	1.08E+06	3.25E+05	2.61E+06	1.31E+04	2.82E+03	5.10E+04	
TOTAL FOR MASS BAYS WITH APPROACH A =					3.88E+06		
TOTAL FOR MASS BAYS WITH APPROACH B =					4.08E+06		

Figure 32. Phosphorus load to Mass Bay by source (mt/yr)



No estimates were made for
dredged material or groundwater

Figure 33. Relative contributions to Mass Bay phosphorus load.



6.1.6 Oil and Grease

Loadings of oil and grease to Massachusetts Bay are summarized in Table 96 and Figures 34 and 35. No estimates have been developed for atmospheric loadings. Total loadings are estimated to be 13,000 metric tons using Method A and 6,100 metric tons using Method B. The reason for the two-fold difference is that no estimate was developed for river discharges in Method B. Method B is therefore considered an incomplete estimate.

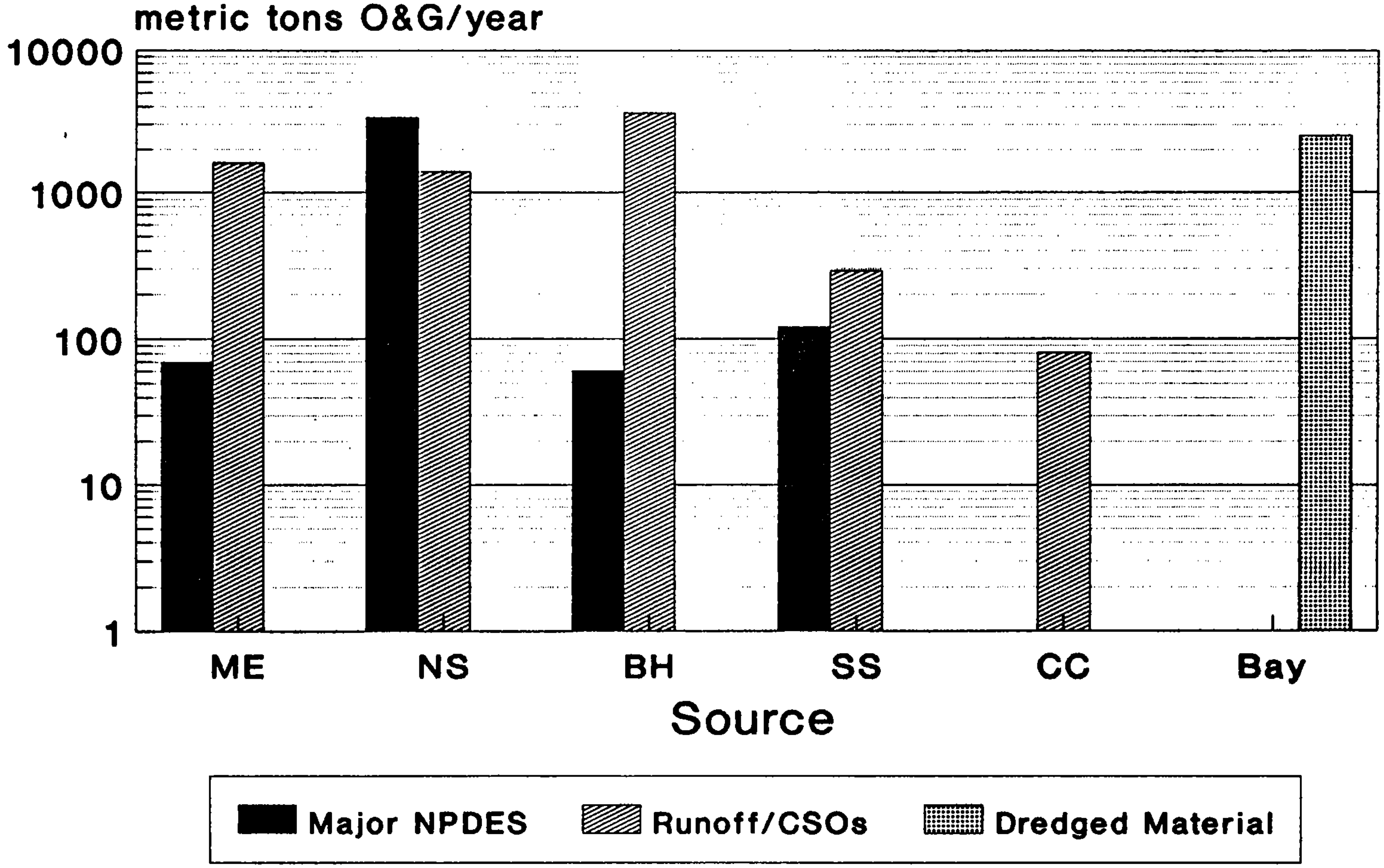
Based on the available estimates, it appears that nonpoint source runoff dominates the loading of oil and grease. Inputs from CSOs are estimated as 1,700 , and nonCSO inputs are estimated as 5,300 metric tons annually. Unfortunately, we have no measurements of variability or uncertainty in these estimates.

Dredged material disposal is also a major source for this pollutant category and accounts for 19% of the load estimated using Method A.

Table 96. Oil and grease load to Massachusetts Bay by source (kg/yr).

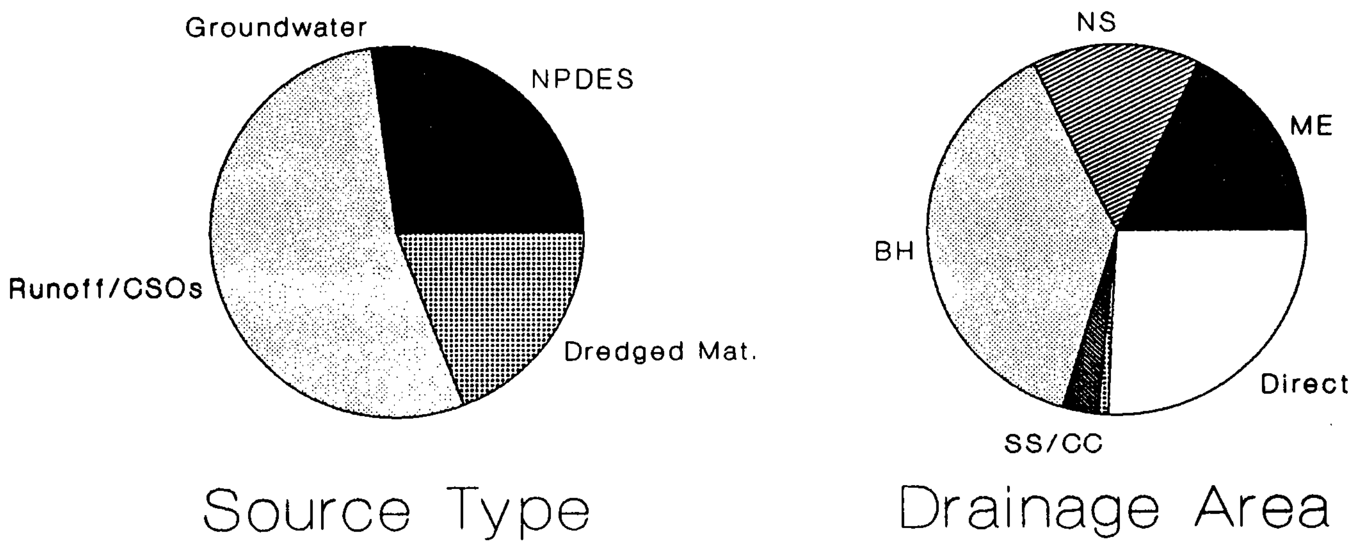
Oil and Grease kg/yr Source	Drainage Area: Merrimack	North Shore	Boston Harbor	South Shore	Cape Cod	Direct	Totals
Drainage Area Calculation Using Method A	NOTE THIS TABLE NEEDS TO BE CORRECTED PENDING QA REVIEW						
NPDES	6.97E+04	3.36E+06	6.11E+04	1.17E+04			3.50E+06
Runoff/CSOs (1)	1.64E+06	1.37E+06	3.63E+06	2.93E+05	8.18E+04		6.93E+06
Groundwater	NA	NA	NA	NA	NA		0.00E+00
Totals =	1.71E+06	4.73E+06	3.69E+06	3.05E+05	8.18E+04	0.00E+00	1.04E+07
Drainage Area Calculation Using Method B							
Coastal NPDES		3.36E+06	6.11E+04	1.17E+04			3.43E+06
Coastal Runoff/CSOs (1)	4.93E+03	4.10E+04	7.26E+04	2.34E+04	4.91E+04		1.42E+05
River Discharge (no estimates were developed)							0.00E+00
Groundwater	NA	NA	NA	NA	NA		0.00E+00
Totals =	4.93E+03	3.40E+06	1.34E+05	3.51E+04	4.91E+04	0.00E+00	3.57E+06
Direct Sources to Mass Bays							
Atmosphere (no estimates were developed)							0.00E+00
Dredge Material						2.46E+06	2.46E+06
Totals with Approach A	1.71E+06	4.73E+06	3.69E+06	3.05E+05	8.18E+04	2.46E+06	
Totals with Approach B	4.93E+03	3.40E+06	1.34E+05	3.51E+04	4.91E+04	2.46E+06	
TOTAL FOR MASS BAYS WITH APPROACH A =					1.30E+07		
TOTAL FOR MASS BAYS WITH APPROACH B =					6.08E+06		

Figure 34. Oil and grease load to Mass Bay by source (mt/yr)



No estimates were made for atmospheric loadings

Figure 35. Relative contributions to Mass Bay load of oil and grease.



207

6.1.7 PAHs

The loadings of PAHs to Massachusetts Bay are provided in Tables 97 and 98 and in Figures 36 to 38 Loadings estimates for PAHs are provided for several cases involving Methods A and B and higher and lower estimates. We present this range to illustrate the kind of variability (i.e., range) there exists in the estimates. Because of uncertainty in the data we used and the estimates we made, the lower and higher values should not be considered a complete range.

For the NPDES discharges, our higher estimates assume that concentrations of PAHs in municipal effluents average 10 ug/l, and the lower estimates assume average concentrations of 1 ug/l. In fact, average concentrations may be even lower. Preliminary analysis of one grab sample from Deer Island effluent and one from Nut Island effluent has indicated that no individual PAH compound is present in concentrations greater than 10 ng/l (personal communication, D. Shea, Battelle). MWRA plans greater, representative sampling and analysis of effluents to confirm these data.

Estimates for loads in runoff and rivers were also estimated, based on assumed concentrations of 0.1 and 1 mg/l in runoff and 50 ng/l in river water. The low estimate for runoff is based on Menzie et al. (1991). The higher estimate was selected as moderate but still low. This level is lower than values found in typical urban soils but may be considered representative of levels that occur in open field or suburban areas. As a basis for comparison, the levels of PAHs in road dust can typically be on the order of 100s of mg/kg. Thus, even though our calculations do not indicate that runoff is a dominant or important source of loadings, had we used somewhat higher values for runoff (i.e., typical or urban areas), runoff estimates could have been a substantial fraction of the total. These value for rivers was selected as typical, assuming that 10-100 ng/l are typical concentrations of PAHs in urban river systems (Menzie et al., 1991).

Using the higher estimates, Methods A and B give approximately the same result, 13,700 and 13,100 kg/yr. These higher estimates are dominated by NPDES discharges (81%) and the discharges to the Boston Harbor drainage area account for 76% of the NPDES load. Using the higher estimates, atmospheric inputs and dredge material disposal are about an order of magnitude less than the NPDES inputs.

If the lower estimates are used the following results are obtained (Table **Error! Bookmark not defined.**). The total estimated loads are 1,810 kg/yr for Method A and 2,200 kg/yr for Method B. NPDES discharges account for 45% (Method A) and 34% (Method B) of the total load. The potential importance of the atmosphere as the dominant source emerges when lower estimates are employed: 52% of the load for Method A and 43% for Method B.

Table 97. Higher estimate of PAH loading by source (kg/yr).

PAHs: higher estimate	Drainage Area						
kg/yr		North	Boston	South	Cape		
Source	Merrimack	Shore	Harbor	Shore	Cod	Direct	Totals
Drainage Area Calculation							
Using Method A							
NPDES	8.16E+02	1.70E+03	8.41E+03	1.38E+02			1.11E+04
Runoff/CSOs (1)	9.09E+01	4.59E+01	8.64E+01	7.09E+00	1.96E+00		2.30E+02
Groundwater	NA	NA	2.00E-01	NA	NA		2.00E-01
Totals =	9.07E+02	1.75E+03	8.50E+03	1.45E+02	1.96E+00	0.00E+00	1.13E+04
Drainage Area Calculation							
Using Method B							
Coastal NPDES	4.75E+00	1.68E+03	8.39E+03	1.38E+02			1.02E+04
Coastal Runoff/CSOs (1)	2.00E-02	1.20E+00	1.55E+00	5.68E-01	1.96E+00		3.34E+00
River Discharge	3.84E+02	2.22E+01	5.68E+01	1.34E+01			4.76E+02
Groundwater	NA	NA	2.00E-01	NA	NA		2.00E-01
Totals =	3.89E+02	1.70E+03	8.45E+03	1.52E+02	1.96E+00	0.00E+00	1.07E+04
Direct Sources to Mass Bays							
Atmosphere						1.26E+03	1.26E+03
Dredge Material						1.16E+03	1.16E+03
Totals with Approach A	9.07E+02	1.75E+03	8.50E+03	1.45E+02	1.96E+00	2.42E+03	
Totals with Approach B	3.89E+02	1.70E+03	8.45E+03	1.52E+02	1.96E+00	2.42E+03	
TOTAL FOR MASS BAYS WITH APPROACH A =					1.37E+04		
TOTAL FOR MASS BAYS WITH APPROACH B =					1.31E+04		
1. Assumes a concentration of 1 mg/kg PAH in solids carried in runoff.							

Table 98. Lower estimate of PAH loading by source (kg/yr).

PAHs: lower estimate	**Drainage Area**						
kg/yr		**North**	**Boston**	**South**	**Cape**		
Source	**Merrimack**	**Shore**	**Harbor**	**Shore**	**Cod**	**Direct**	**Totals**
Drainage Area Calculation Using Method A							
NPDES	1.36E+02	1.54E+02	7.38E+02	2.18E+01			1.05E+03
Runoff/CSOs (1)	9.09E+00	4.59E+00	8.64E+00	7.09E-01	1.96E-01		2.30E+01
Groundwater	NA	NA	2.00E-01	NA	NA		2.00E-01
Totals =	1.45E+02	1.59E+02	7.47E+02	2.25E+01	1.96E-01	0.00E+00	1.07E+03
Drainage Area Calculation Using Method B							
Coastal NPDES		1.54E+02	7.38E+02	2.18E+01			9.14E+02
Coastal Runoff/CSOs (1)	2.00E-03	1.20E-01	1.55E-01	5.68E-02	1.96E-01		3.34E-01
River Discharge	3.84E+02	2.22E+01	5.68E+01	1.34E+01			4.76E+02
Groundwater	NA	NA	2.00E-01	NA	NA		2.00E-01
Totals =	3.84E+02	1.77E+02	7.95E+02	3.53E+01	1.96E-01	0.00E+00	1.39E+03
Direct Sources to Mass Bays							
Atmosphere						9.53E+02	9.53E+02
Dredge Material						1.16E+01	1.16E+01
Totals with Approach A	1.45E+02	1.59E+02	7.47E+02	2.25E+01	1.18E+01	9.65E+02	
Totals with Approach B	3.84E+02	1.77E+02	7.95E+02	3.53E+01	1.18E+01	9.65E+02	
TOTAL FOR MASS BAYS WITH APPROACH A =					2.05E+03		
TOTAL FOR MASS BAYS WITH APPROACH B =					2.37E+03		
1. Assumes a concentration of 0.1 mg/kg PAH on solids carried in runoff							

Figure 36. PAH load to Massachusetts Bay by source (kg/yr, lower estimate)

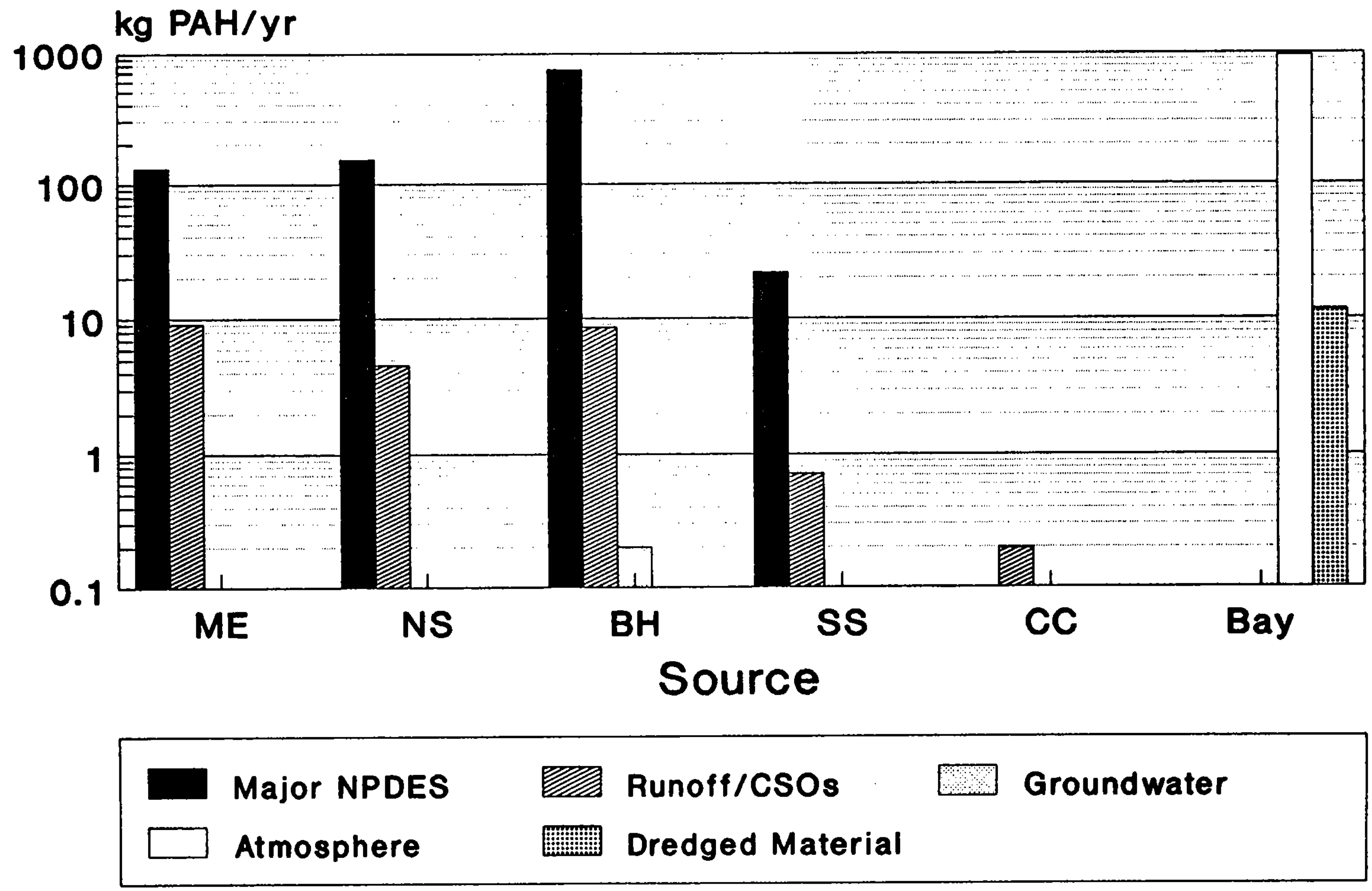
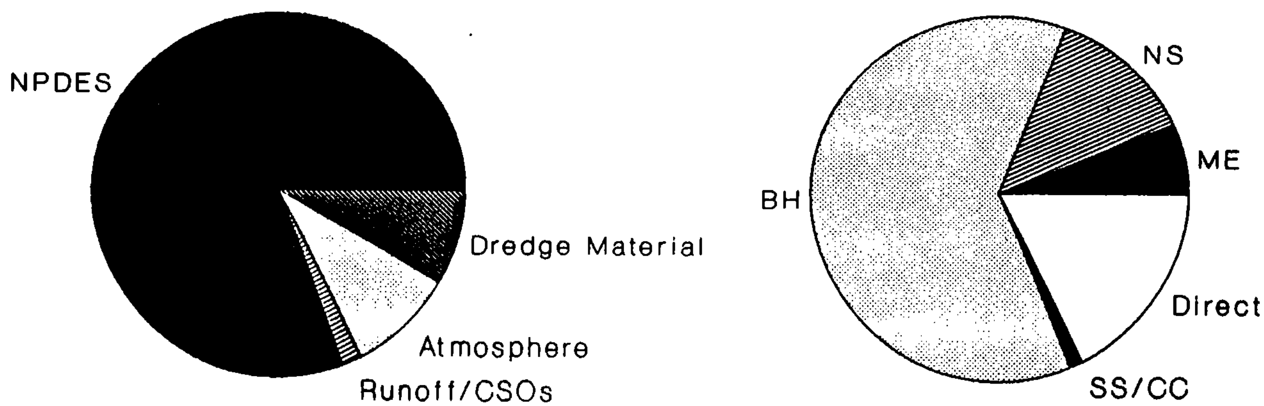


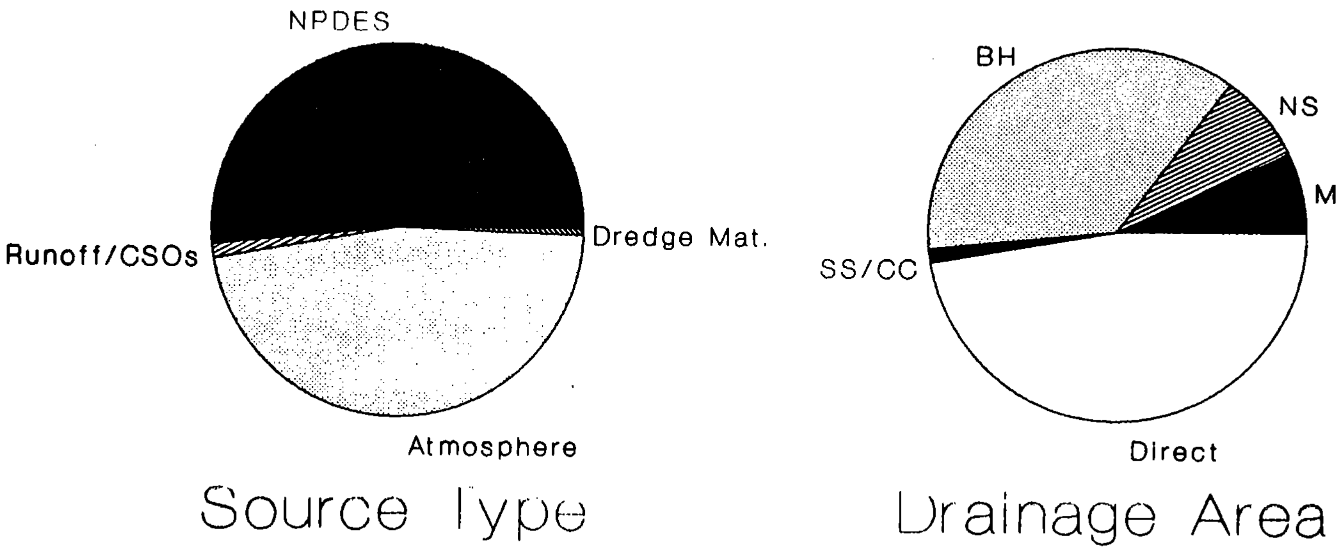
Figure 37. Relative contributions to PAH load based on higher estimates.



Source Type

Drainage Area

Figure 38. Relative contribution to PAH load based on lower estimate.



6.1.8 PCBs

Loadings of PCBs to Massachusetts Bay are summarized in Table 99 and Figures 39 and 40. Total loadings are estimated to be approximately 2,600 kg/yr for both Method A
and B.

The reason that Methods A and B give almost identical results is that the loading is dominated by atmospheric inputs which account for about 85% of the total load. The estimates of atmospheric load are based on data collected during the mid 1970s, and, therefore, may be substantially higher than current levels. Because production of PCBs declined in the late 1970s, it is likely that concentrations of these compounds are declining. Still, Atlas et al. (1986) point out that the atmosphere is the major source of PCBs to the oceans and they estimate that 98% of the PCBs entering the oceans is currently being deposited from the atmosphere. For the oceans as a whole their estimate is 1,700,000 kg/yr or about three orders of magnitude greater than our estimate for Massachusetts Bay.

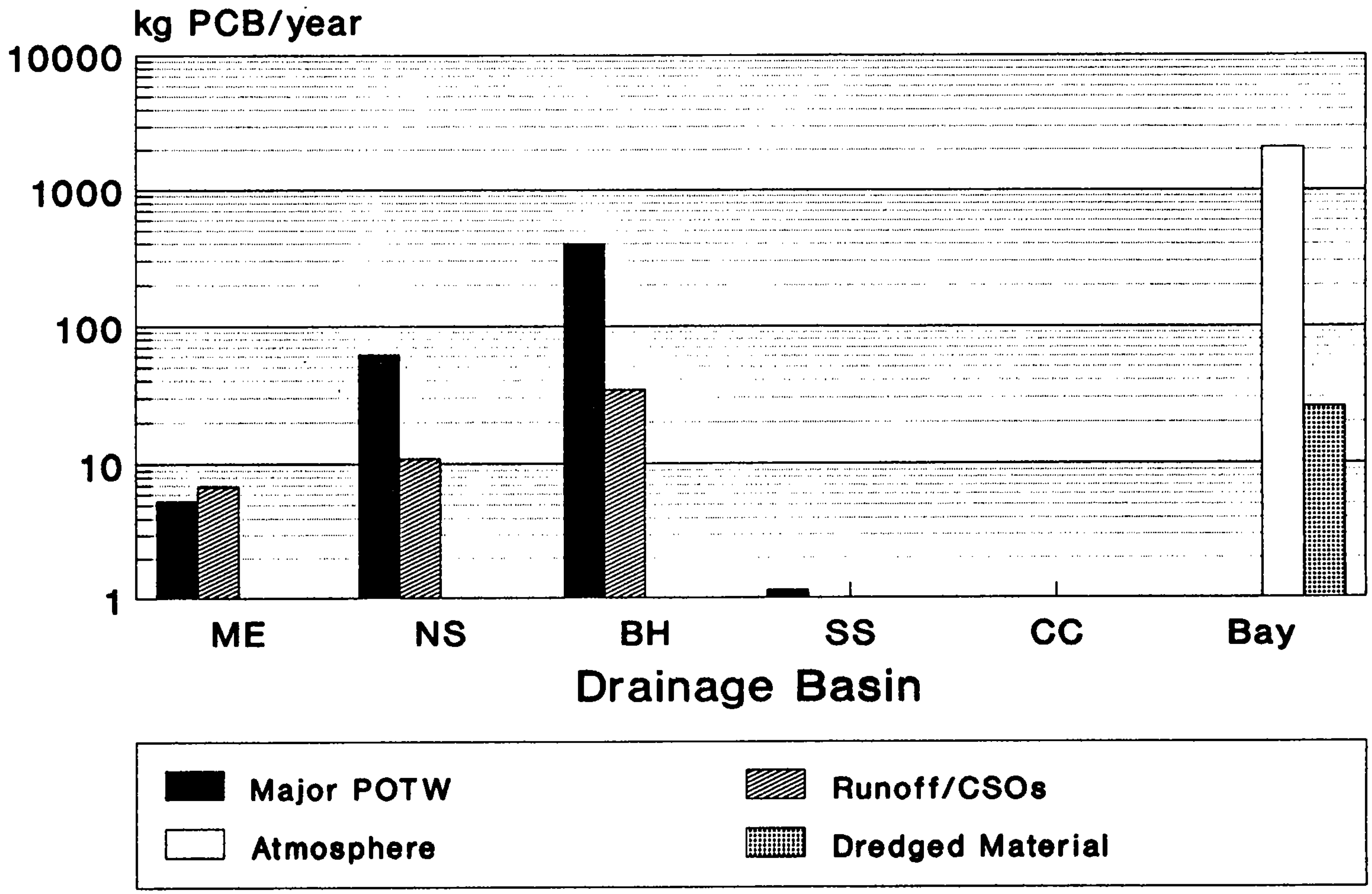
Our estimates of inputs from NPDES discharges ranged from 416-468 kg/yr. Using the higher of these estimates, point sources accounted for about 20% of the inputs to the bays. These estimates are probably too high however, because they are based upon data that were below detection limits. These estimates are likely to decline, when the MWRA completes analyses of additional effluent samples. Preliminary data from the MWRA indicates that no individual PCB compound is present in effluent at concentrations greater than 10 ng/l.

THIS PAGE INTENTIONALLY LEFT BLANK

Table 99. PCB load to Mass Bay by source (kg/yr).

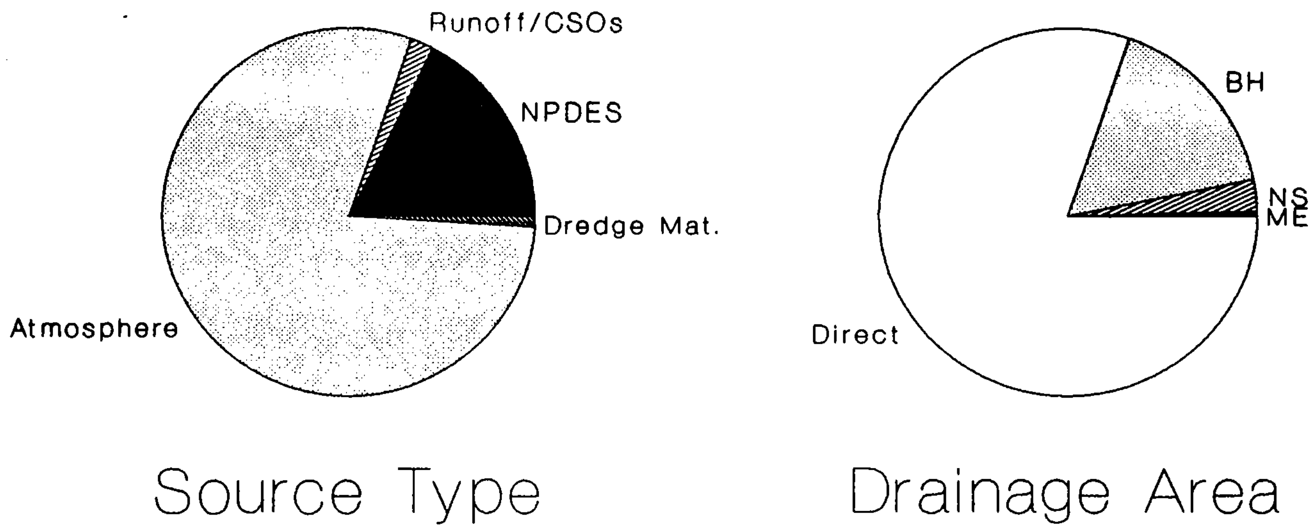
PCBs kg/yr Source	Drainage Area Merrimack	North Shore	Boston Harbor	South Shore	Cape Cod	Direct	Totals
Drainage Area Calculation Using Method A							
NPDES	5.40E+00	6.16E+01	4.00E+02	1.14E+00			4.68E+02
Runoff/CSOs (1)	6.80E+00	1.08E+01	3.41E+01				5.17E+01
Groundwater	NA	NA	NA	NA	NA		0.00E+00
Totals =	1.22E+01	7.24E+01	4.34E+02	1.14E+00	0.00E+00	0.00E+00	5.20E+02
Drainage Area Calculation Using Method B							
Coastal NPDES		6.16E+01	4.00E+02	1.14E+00			4.63E+02
Coastal Runoff/CSOs (1)			1.00E+00				1.00E+00
River Discharge	7.70E+00	7.00E-02	4.00E-02	6.00E-03			7.82E+00
Groundwater	NA	NA	2.00E-01	NA	NA		2.00E-01
Totals =	7.70E+00	6.17E+01	4.01E+02	1.15E+00	0.00E+00	0.00E+00	4.72E+02
Direct Sources to Mass Bays							
Atmosphere						2.10E+03	2.10E+03
Dredge Material						2.55E+01	2.55E+01
Totals with Approach A	1.22E+01	7.24E+01	4.34E+02	1.14E+00	0.00E+00	2.12E+03	
Totals with Approach B	7.70E+00	6.17E+01	4.01E+02	1.15E+00	0.00E+00	2.12E+03	
TOTAL FOR MASS BAYS WITH APPROACH A =					2.64E+03		
TOTAL FOR MASS BAYS WITH APPROACH B =					2.59E+03		

Figure 39. PCB load to Mass Bay
by source (kg/yr).



Estimates include all point/nonpoint

Figure 40. Relative contributions to Mass Bay load of PCBs.



6.1.9 Metals

We selected the following metals for presentation: cadmium, chromium, copper, lead, zinc, and mercury. These appear to be six of the more important metals from a human health and/or ecological standpoint in the system and have been observed at elevated levels in the Massachusetts Bay system.

Cadmium

Loadings of cadmium are summarized in Table 100 and in Figures 41 and 42. There is considerable uncertainty in the cadmium estimates because there are few measurements for point sources. We have addressed this lack of data, in part, by estimating cadmium concentrations for various POTWs based upon the cadmium:TSS ratio in Deer Island effluent. We feel this is reasonable because Deer Island effluent integrates a wide variety of inputs. TSS is generally measured for these effluents. With the TSS-based estimates, the our estimates of cadmium entering the bays ranged from 2,260-2,620 kg/yr.

Using the higher estimates for all sources we obtain cadmium loadings of 8,020 kg/yr and 14,700 kg/yr for Methods A and B respectively. NPDES discharges account for 34% and 17% of the Method A and B estimates. Most of this load is associated with the Boston Harbor drainage area (78% of the Method A NPDES load).

Nonpoint sources appear to be relatively important sources. Runoff in Method A accounts for 30% of the load and river discharge in Method B accounts for 66% of the load. The runoff estimate was made using the NCPDI, with values for CSO inputs corrected for concentrations measured by the MWRA. CSOs accounted for most of the cadmium inputs. Our estimate of inputs from rivers assumed an average concentration in river water of 1 ug/l. Values reported in the literature ranged from 0.01-7 ug/l, so our estimates of total contribution for rivers would vary substantially if we selected a different value.

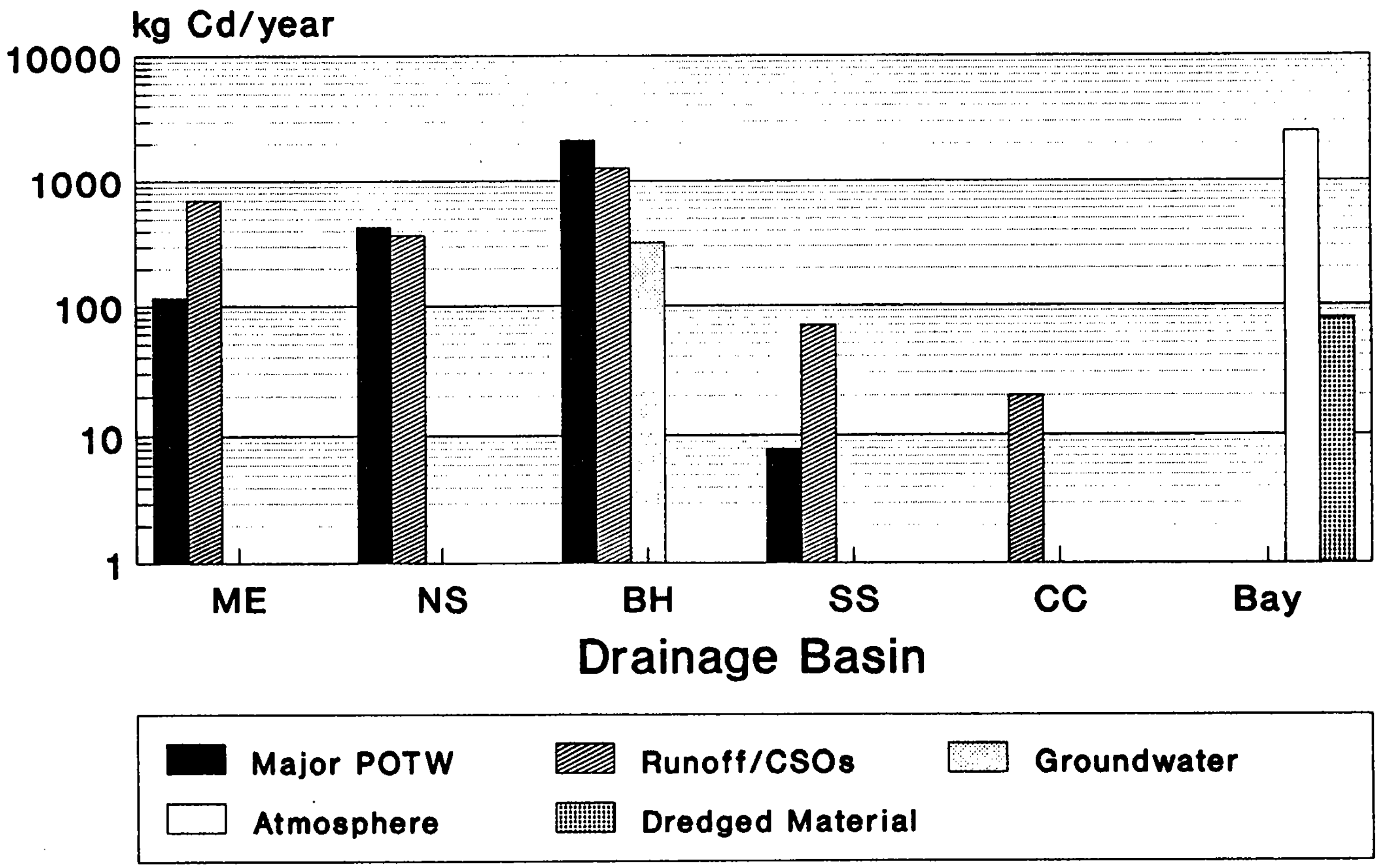
The atmosphere contributes 31% for Method A and 17% for Method B. Very few data were available upon which to base the estimate of atmospheric inputs, and our estimate, the only one we made, is considered to be high.

Groundwater discharge to Boston Harbor was estimated to be about 15% of the point source load, using our higher estimate of 320 kg/yr. Our lower estimate was only 10% that value.

Table 100. Cadmium load to Mass Bay by source (kg/yr).

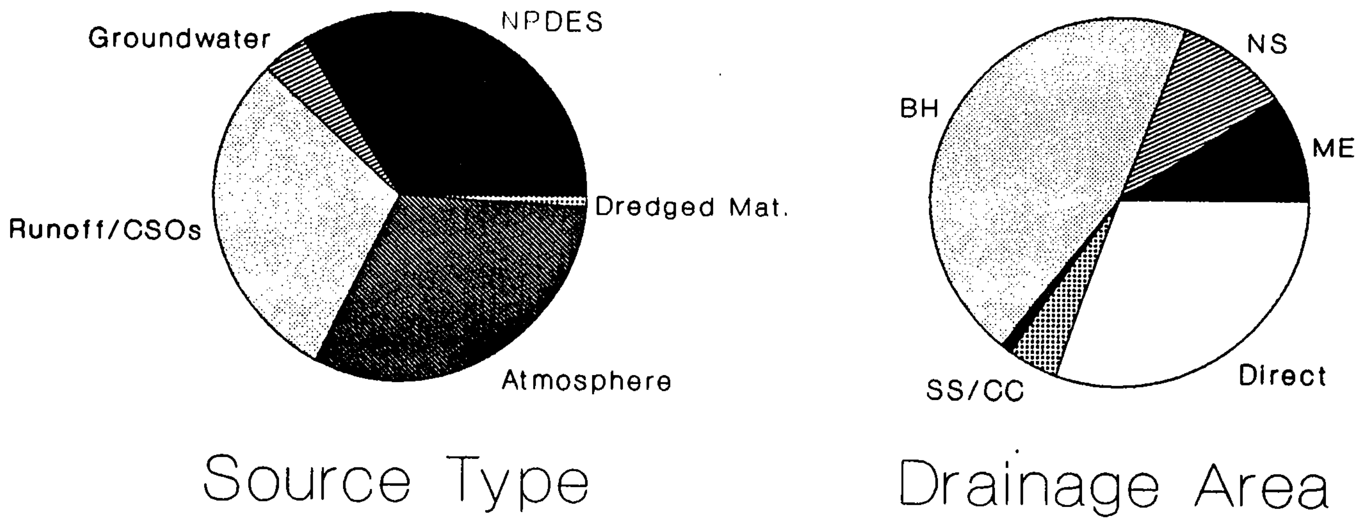
Cadmium kg/yr Source	Drainage Area Merrimack	North Shore	Boston Harbor	South Shore	Cape Cod	Direct	Totals
Drainage Area Calculation Using Method A							
NPDES	1.16E+02	4.30E+02	2.14E+03	7.90E+00			2.70E+03
Runoff/CSOs	6.95E+02	3.68E+02	1.27E+03	6.90E+01	2.00E+01		2.40E+03
Groundwater	NA	NA	3.20E+02	NA	NA		3.20E+02
Totals =	8.11E+02	7.98E+02	3.73E+03	7.69E+01	2.00E+01	0.00E+00	5.42E+03
Drainage Area Calculation Using Method B							
Coastal NPDES		4.30E+02	2.07E+03	7.90E+00			2.51E+03
Coastal Runoff/CSOs	1.00E+00	1.00E+01	1.70E+01	6.00E+00	2.00E+01		3.40E+01
River Discharge	7.69E+03	4.45E+02	1.14E+03	2.67E+02	0.00E+00		9.54E+03
	NA	NA	NA	NA	NA		0.00E+00
Totals =	7.69E+03	8.85E+02	3.23E+03	2.81E+02	2.00E+01	0.00E+00	1.21E+04
Direct Sources to Mass Bays							
Atmosphere						2.50E+03	2.50E+03
Dredged Material						7.88E+01	7.88E+01
Totals with Approach A	8.11E+02	7.98E+02	3.73E+03	7.69E+01	2.00E+01	2.58E+03	
Totals with Approach B	7.69E+03	8.85E+02	3.23E+03	2.81E+02	2.00E+01	2.58E+03	
TOTAL FOR MASS BAYS WITH APPROACH A =					8.02E+03		
TOTAL FOR MASS BAYS WITH APPROACH B =					1.47E+04		

Figure 41. Cadmium load to Mass Bay by source (kg/yr).



Estimates include all point/nonpoint
Groundwater estimated for BH only

Figure 42. Relative contributions to cadmium load.



Chromium

Chromium loadings are summarized in Table 101 and Figures 43 and 44. We have presented the higher estimates of loadings for the sources. In the case of NPDES dischargers we have mad estimates for a number of the POTWs by applying a Cr:TSS factor derived from averaging data for several other POTWs in the Massachusetts Bay system.

Methods A and B yielded total loadings of 84,000 kg/yr and 120,000 kg/yr respectively. NPDES dischargers accounted for 53% of the Method A estimate and 35% of the Method B estimate. Our estimates of inputs from NPDES discharges were essentially the same.

Dredged material disposal accounted for 14% and 10% of the two estimates.

Nonpoint sources of runoff accounted for 24% of the load for Method A and rivers accounted for 47% of the load for Method B. Runoff estimates were calculated using the NCPDI, as corrected for concentrations measured in CSOs. NonCSO urban runoff accounted for more than half the total estimate of runoff.

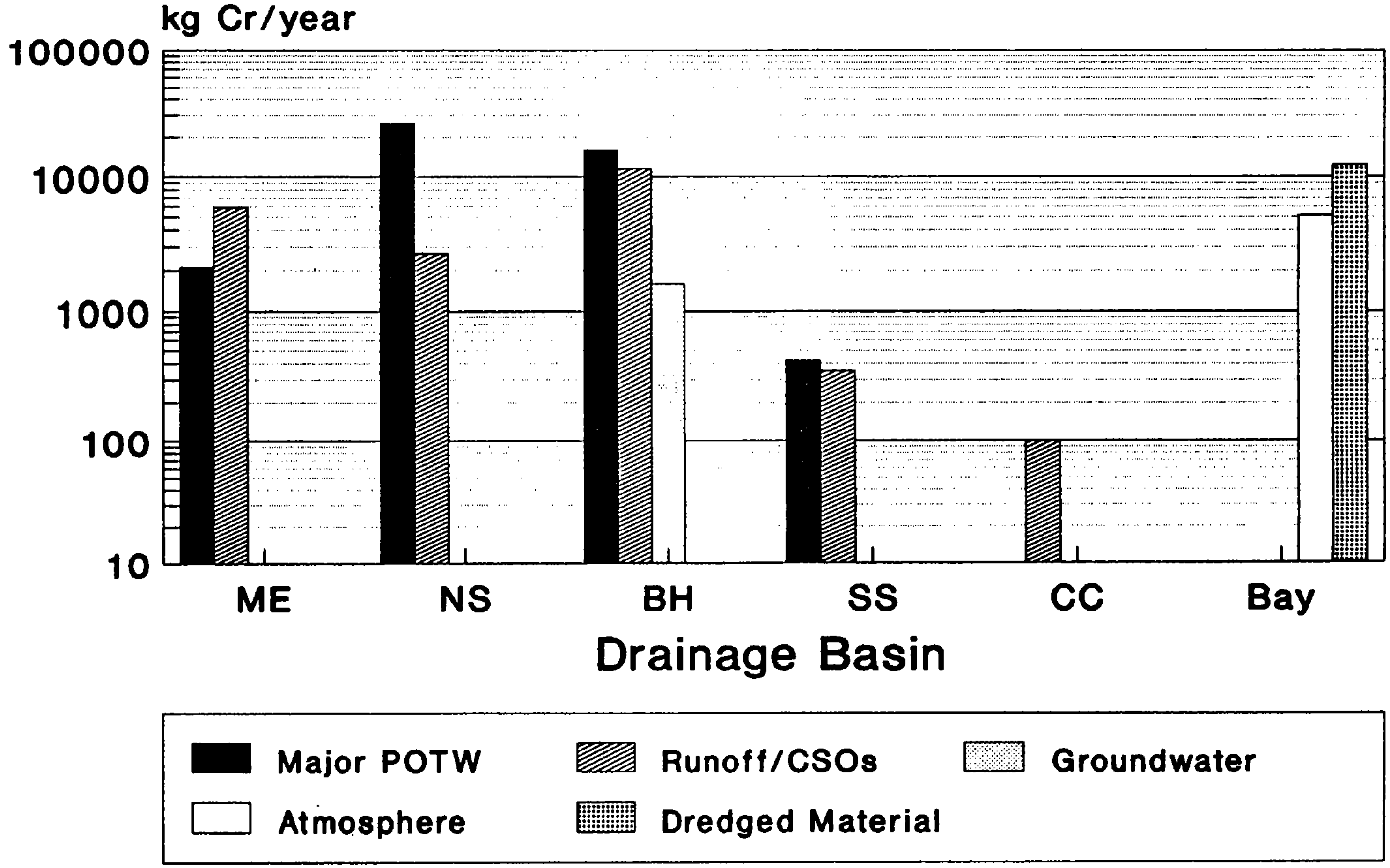
Inputs from rivers accounted for about one half of the Method B estimate. This estimate assumes an average concentration of chromium in river waters of 6 ug/l. Values reported in the literature ranged from 1-30 ug/l.

Using our higher estimate of atmospheric deposition of chromium, 5,110 kg/yr, the atmosphere accounted for only a minor contribution to the total load. Our lower estimate of atmospheric deposition of chromium was only 145 kg/yr, so the contribution is probably minimal.

Table 101. Chromium load to Mass Bay by source (kg/yr).

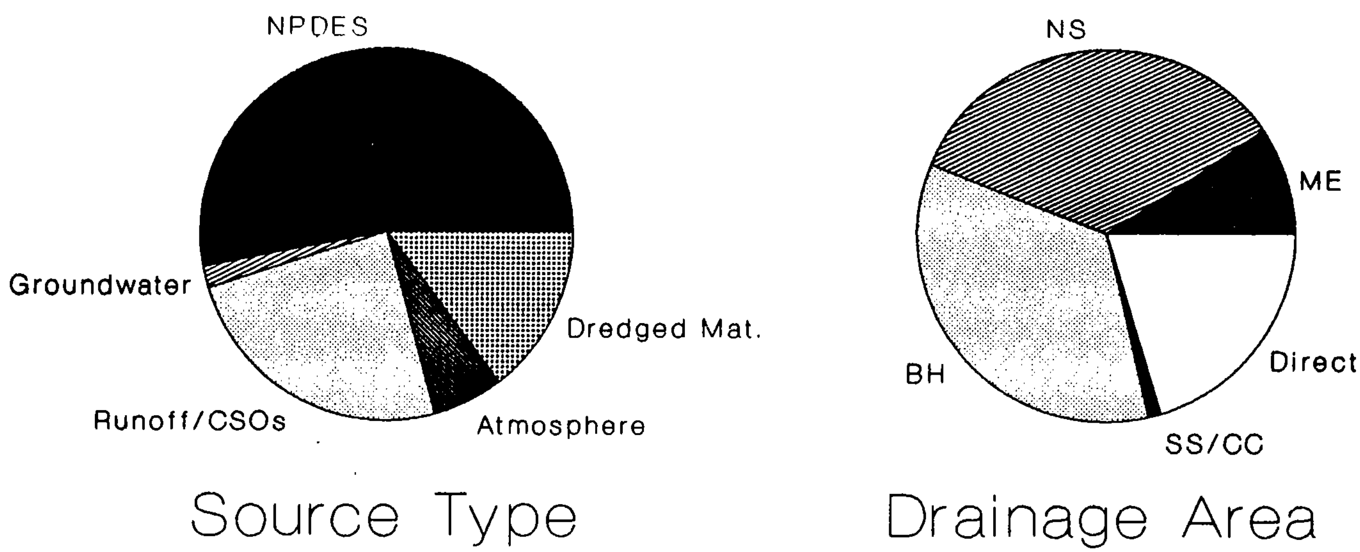
Chromium	Drainage Area						
kg/yr		North	Boston	South	Cape		
Source	Merrimack	Shore	Harbor	Shore	Cod	Direct	Totals
Drainage Area Calculation Using Method A							
NPDES	2.10E+03	2.60E+04	1.60E+04	4.30E+02			4.45E+04
Runoff/CSOs	5.86E+03	2.67E+03	1.15E+04	3.55E+02	1.00E+02		2.04E+04
Groundwater	NA	NA	1.60E+03	NA	NA		1.60E+03
Totals =	7.96E+03	2.87E+04	2.91E+04	7.85E+02	1.00E+02	0.00E+00	6.65E+04
Drainage Area Calculation Using Method B							
Coastal NPDES		2.60E+04	1.57E+04	4.30E+02			4.21E+04
Coastal Runoff/CSOs	1.00E+01	7.50E+01	9.40E+01	2.80E+01	1.00E+02		2.07E+02
River Discharge	4.61E+04	2.67E+03	6.82E+03	1.60E+03			5.72E+04
Groundwater			1.60E+03				1.60E+03
Totals =	4.61E+04	2.87E+04	2.42E+04	2.06E+03	1.00E+02	0.00E+00	1.01E+05
Direct Sources to Mass Bays							
Atmosphere						5.11E+03	5.11E+03
Dredge Material						1.23E+04	1.23E+04
Totals with Approach A	7.96E+03	2.87E+04	2.91E+04	7.85E+02	1.00E+02	1.74E+04	
Totals with Approach B	4.61E+04	2.87E+04	2.42E+04	2.06E+03	1.00E+02	1.74E+04	
TOTAL FOR MASS BAYS WITH APPROACH A =					8.40E+04		
TOTAL FOR MASS BAYS WITH APPROACH B =					1.19E+05		

Figure 43. Chromium load to Mass Bay by source (kg/yr).



Estimates include all point/nonpoint
Groundwater estimated for BH only

Figure 44. Relative contributions to chromium load.



Copper

Loadings of copper (higher estimates) are provided in Table 102 and Figures 45 and 46. Because we had data for many of the POTWs for copper, we elected not to estimate loadings for those few for which data were lacking.

Methods A and B gave good agreement for total loadings with 150,000 kg/yr and 190,000 kg/yr respectively. Point and nonpoint sources were both important contributors to the overall loads.

NPDES dischargers accounted for 57% and 37% of the loads for Methods A and B respectively. The Boston Harbor Drainage Area accounted for about 76% of the NPDES load under Method A. Our estimates of total copper inputs ranged from 76,300 to 86,700 kg/yr.

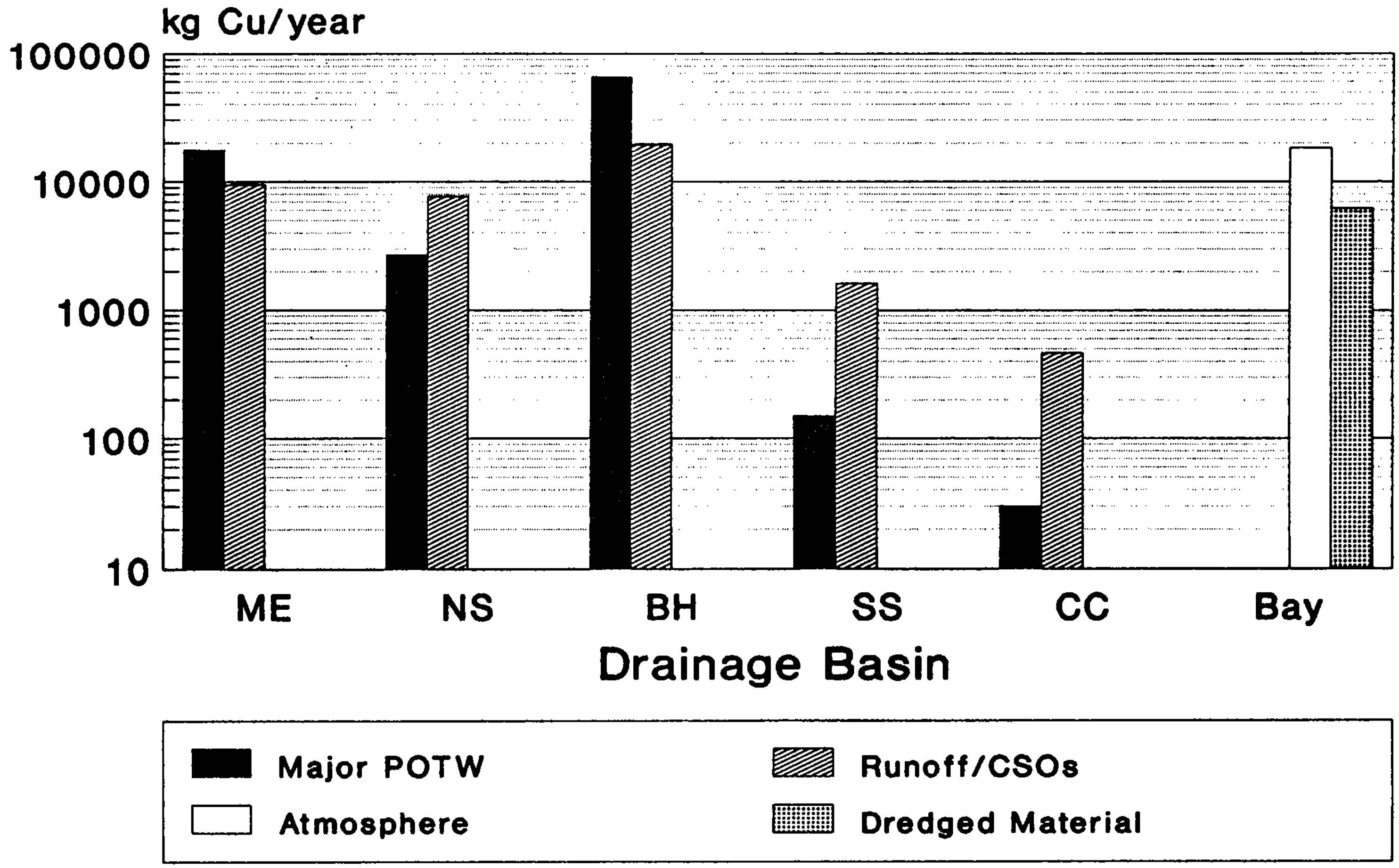
Runoff amounted to 25% of the load for Method A while riverine inputs amounted to 50% of the load under Method B. NonCSO urban runoff accounted for most of the inputs from runoff. Our estimate of inputs from rivers assumed an average concentration in river water of 10 ug/l.

The atmosphere contributed to 12% and 9% of the load for the two methods, using our estimate of about 20,000 kg/yr. Dredged material contributed 4% of the load under Method A. We have no range of estimates for these inputs.

Table 102. Copper load to Mass Bay by source (kg/yr).

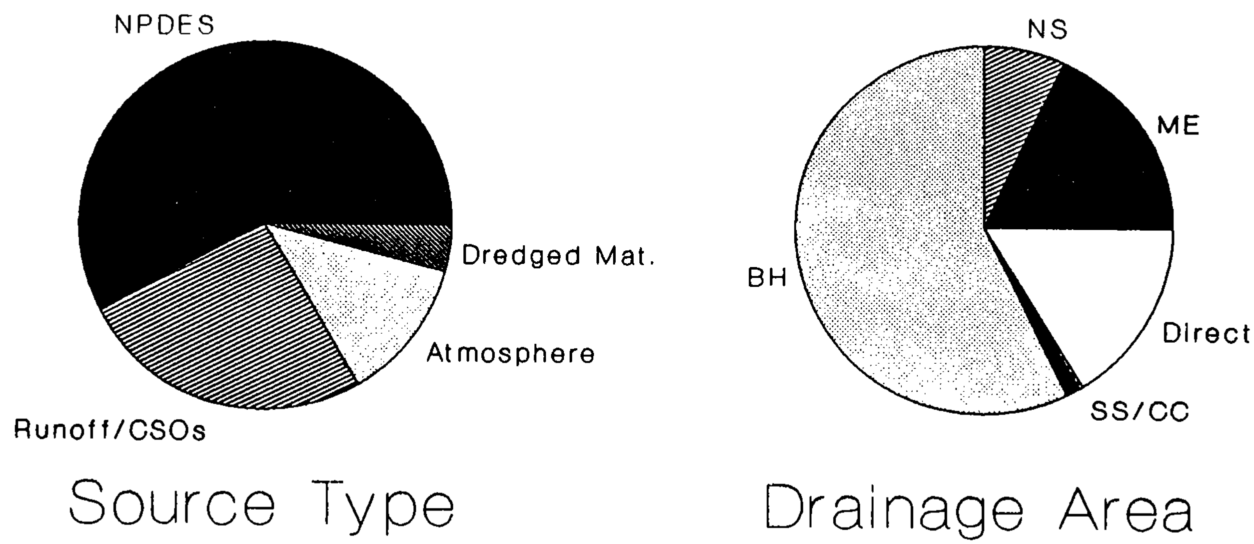
Copper	Drainage Area						
kg/yr		North	Boston	South	Cape		
Source	Merrimack	Shore	Harbor	Shore	Cod	Direct	Totals
Drainage Area Calculation Using Method A							
NPDES	1.77E+04	2.69E+03	6.60E+04	1.50E+02	3.00E+01		8.65E+04
Runoff/CSOs	9.54E+03	7.67E+03	1.95E+04	1.62E+03	4.66E+02		3.83E+04
Groundwater							0.00E+00
Totals =	2.72E+04	1.04E+04	8.55E+04	1.77E+03	4.96E+02	0.00E+00	1.25E+05
Drainage Area Calculation Using Method B							
Coastal NPDES		2.69E+03	6.60E+04	1.50E+02	3.00E+01		6.88E+04
Coastal Runoff/CSOs	2.90E+01	2.30E+02	3.90E+02	1.30E+02	4.66E+02		7.79E+02
River Discharge	7.69E+04	4.45E+03	1.14E+04	2.67E+03			9.54E+04
Groundwater							0.00E+00
Totals =	7.69E+04	7.37E+03	7.78E+04	2.95E+03	4.96E+02	0.00E+00	1.65E+05
Direct Sources to Mass Bays							
Atmosphere						1.84E+04	1.84E+04
Dredge Material						6.18E+03	6.18E+03
Totals with Approach A	2.72E+04	1.04E+04	8.55E+04	1.77E+03	4.96E+02	2.46E+04	
Totals with Approach B	7.69E+04	7.37E+03	7.78E+04	2.95E+03	4.96E+02	2.46E+04	
TOTAL FOR MASS BAYS WITH APPROACH A =					1.50E+05		
TOTAL FOR MASS BAYS WITH APPROACH B =					1.90E+05		

Figure 45. Copper load to Mass Bay by source (kg/yr).



Estimates include all point/nonpoint
Groundwater was not estimated

Figure 46. Relative contributions to copper load.



Lead

Loadings of lead are provided in Table 103 and Figures 47 and 48. In the case of NPDES dischargers we have made estimates for a number of the POTWs by applying a Pb:TSS factor derived from averaging data for several other POTWs in the Massachusetts Bay system.

Estimates for Methods A and B agreed fairly well yielding loads of 470,000 kg/yr and 540,000 kg/yr respectively. Loads were dominated by nonpoint sources. CSOs and other urban runoff accounted for most of the estimate of inputs from runoff. These values were calculated using the NCPDI. Concentrations of lead in CSO discharges were assumed to be 92 ug/l, as measured by the MWRA, rather than the 474 ug/l used in the NCPDI.

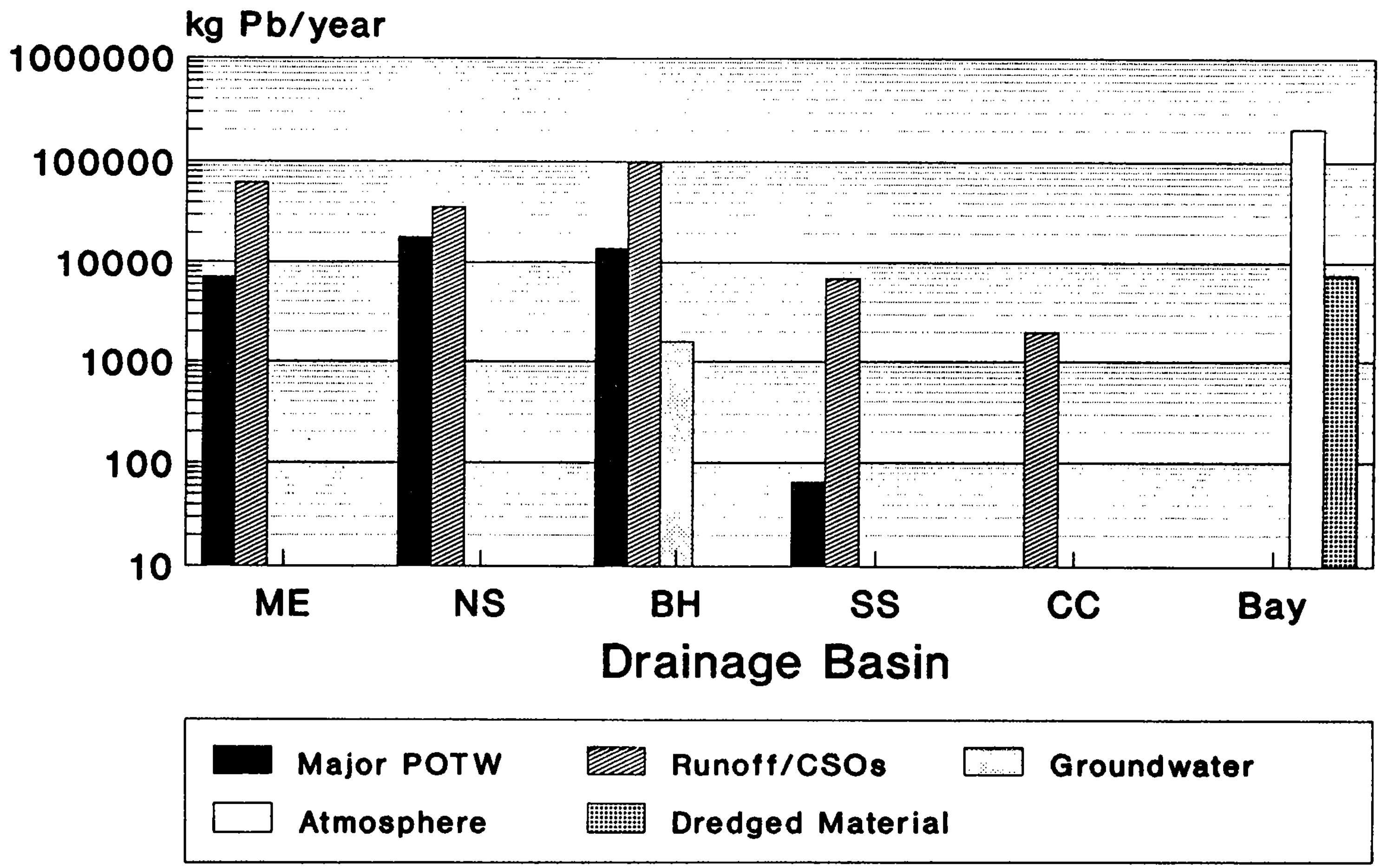
NPDES discharges accounted for less than 10% of the loads using either Method A or B. Runoff accounted for 42% of the load under Method A and river discharge accounted for 54% of the load under Method B. The estimate for river discharge assumes an average concentration of lead in rivers of 30 ug/l. Had an average concentration of 1 ug/l been used, lead inputs from rivers would total 9,540 kg/yr, or only 4% of the total inputs.

Atmospheric inputs were also found to be a major contributor to the total load and accounted for 45% of the Method A estimate and 39% of the Method B estimate, using our estimate of lead deposition, 213,000 kg/yr. Higher estimates of lead deposition have been made for Long Island Sound, so our values may be low.

Table 103. Lead load to Mass Bay by source (kg/yr).

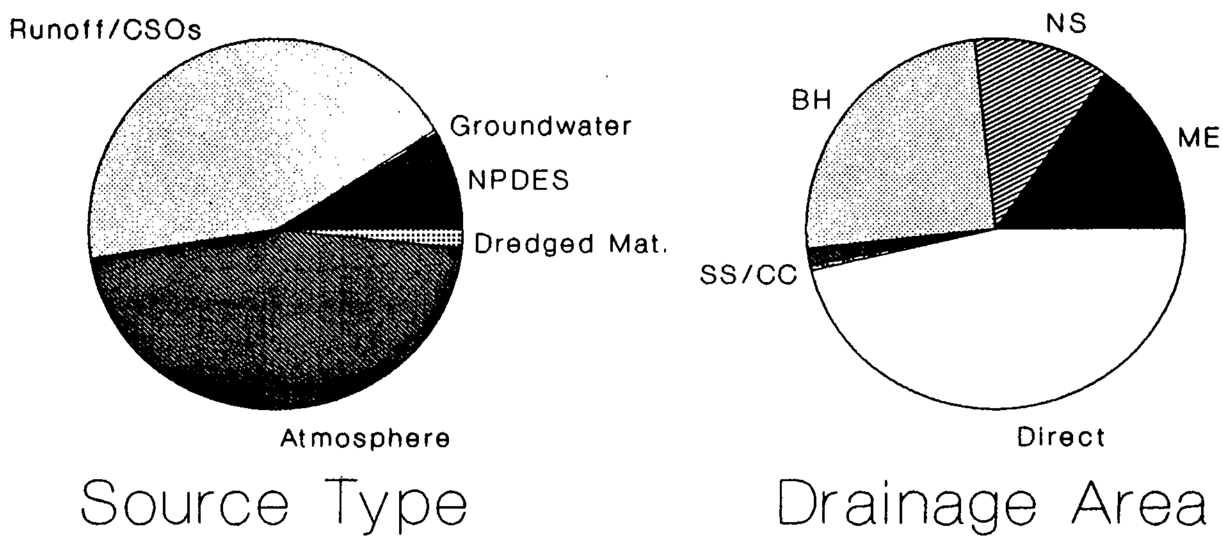
Lead kg/yr Source	Merrimack	North Shore	Boston Harbor	South Shore	Cape Cod	Direct	Totals
			Drainage Area				
Drainage Area Calculation Using Method A							
NPDES	7.10E+03	1.80E+04	1.40E+04	6.50E+01			3.92E+04
Runoff/CSOs	6.23E+04	3.57E+04	9.86E+04	6.82E+03	1.98E+03		2.03E+05
Groundwater			1.60E+03				1.60E+03
Totals =	6.94E+04	5.37E+04	1.14E+05	6.89E+03	1.98E+03	0.00E+00	2.44E+05
Drainage Area Calculation Using Method B							
Coastal NPDES		1.80E+04	1.40E+04	6.50E+01			3.21E+04
Coastal Runoff/CSOs	1.03E+02	7.65E+02	1.29E+03	5.46E+02	1.98E+03		2.70E+03
River Discharge	2.31E+05	1.33E+04	3.41E+04	8.02E+03			2.86E+05
Groundwater							0.00E+00
Totals =	2.31E+05	3.21E+04	4.94E+04	8.63E+03	1.98E+03	0.00E+00	3.21E+05
Direct Sources to Mass Bays							
Atmosphere						2.13E+05	2.13E+05
Dredge Material						7.49E+03	7.49E+03
Totals with Approach A	6.94E+04	5.37E+04	1.14E+05	6.89E+03	1.98E+03	2.21E+05	
Totals with Approach B	2.31E+05	3.21E+04	4.94E+04	8.63E+03	1.98E+03	2.21E+05	
TOTAL FOR MASS BAYS WITH APPROACH A =					4.67E+05		
TOTAL FOR MASS BAYS WITH APPROACH B =					5.44E+05		

Figure 47. Lead load to Mass Bay by source (kg/yr).



Estimates include all point/nonpoint
Groundwater estimated for BH only

Figure 48. Relative contributions to lead load.



Zinc

Loadings of zinc are provided in Table 104 and Figures 49 and 50. Estimates for Methods A and B gave agreed fairly well yielding loads of 419,000 kg/yr and 536,000 kg/yr respectively. Nonpoint sources exceeded point source loadings.

NPDES discharges account for 35% of the loads using Method A and 25% of the load using Method B. Our estimates of zinc inputs from NPDES discharges, based solely upon DMRs, were essentially the same, about 145,000 kg/yr.

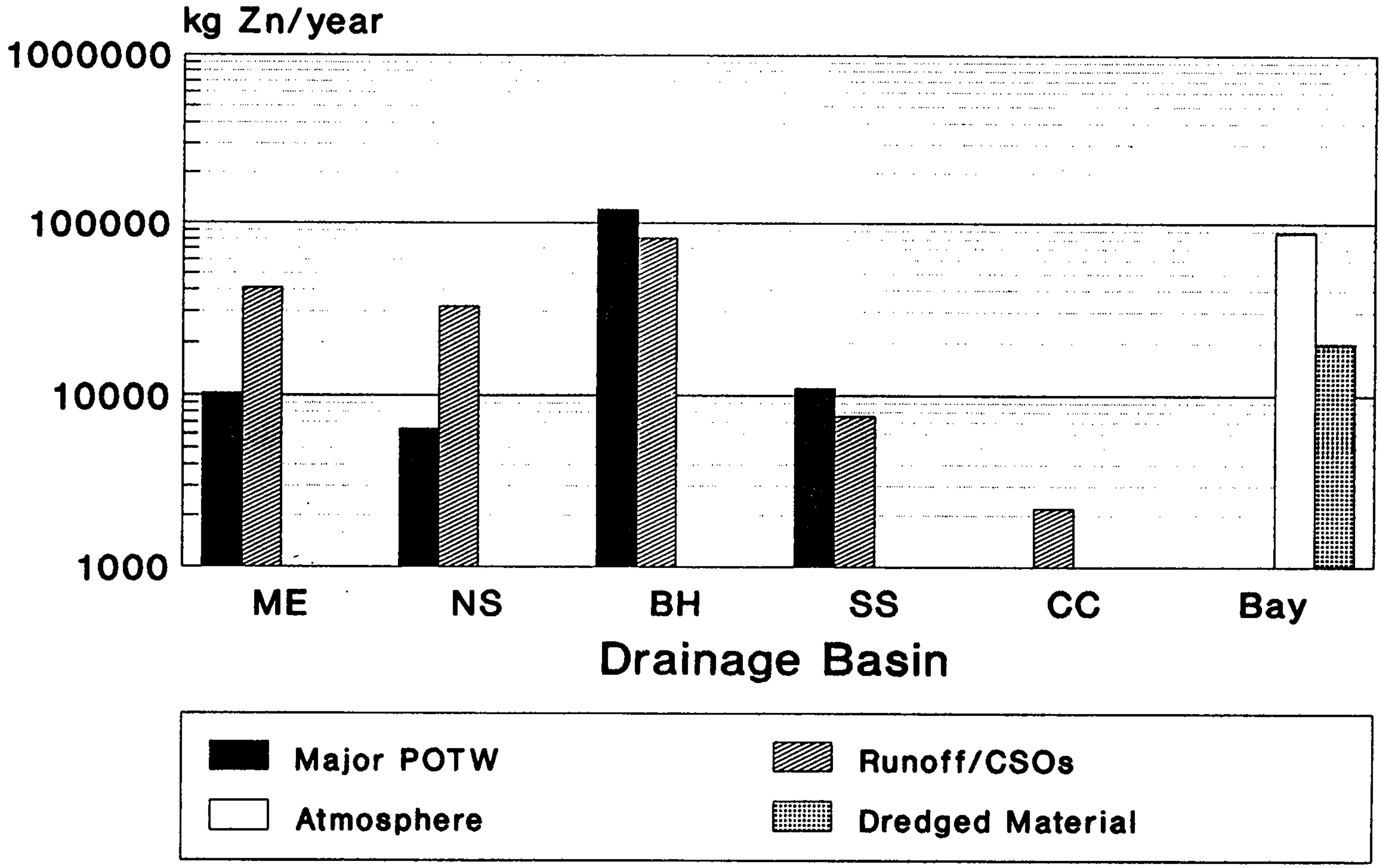
Runoff (including river discharges for B) account for 38% of the load under Method A and 53% of the load under Method B. NonCSO urban inputs accounted for most of the estimate of inputs from runoff. River inputs assumed an average concentration of zinc in rivers of 30 ug/l. The range of concentrations of zinc in U.S. rivers varies widely, from 2 to 50,000 ug/l, so our estimates are subject to considerable uncertainty. Using an estimated 1 ug/l concentration, for example, 9,540 kg/yr enter the system, rather than the 28,600 kg/yr used in our analysis.

Atmospheric inputs and dredged material disposal combined contributed 26% of the load for Method A and 20% of the Method B estimate. Our estimates of inputs of zinc from the atmosphere ranged from 5,000-88,000 kg/yr.

Table 104. Zinc load to Mass Bay by source (kg/yr).

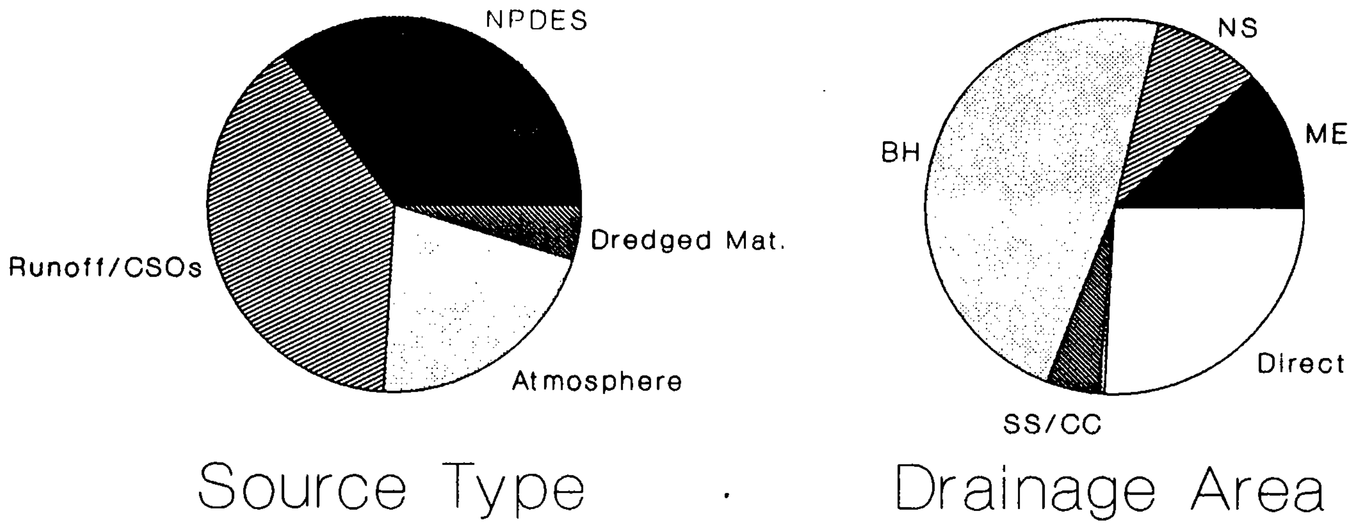
Zinc	Drainage Area						
kg/yr		North	Boston	South	Cape		
Source	Merrimack	Shore	Harbor	Shore	Cod	Direct	Totals
Drainage Area Calculation							
Using Method A							
NPDES	1.03E+04	6.40E+03	1.20E+05	1.10E+04			1.48E+05
Runoff/CSOs (1)	4.10E+04	3.20E+04	8.10E+04	7.60E+03	2.20E+03		1.62E+05
Groundwater	NA	NA	NA	NA	NA		0.00E+00
Totals =	5.13E+04	3.84E+04	2.01E+05	1.86E+04	2.20E+03	0.00E+00	3.09E+05
Drainage Area Calculation							
Using Method B							
Coastal NPDES		6.40E+03	1.20E+05	1.10E+04			1.37E+05
Coastal Runoff/CSOs	1.30E+02	9.50E+02	1.60E+03	6.00E+02	2.20E+03		3.28E+03
River Discharge	2.30E+05	1.30E+04	3.40E+04	8.00E+03			2.85E+05
Groundwater	NA	NA	NA	NA	NA		0.00E+00
Totals =	2.30E+05	2.04E+04	1.56E+05	1.96E+04	2.20E+03	0.00E+00	4.26E+05
Direct Sources to Mass Bays							
Atmosphere						8.80E+04	8.80E+04
Dredge Material						1.98E+04	1.98E+04
Totals with Approach A	5.13E+04	3.84E+04	2.01E+05	1.86E+04	2.20E+03	1.08E+05	
Totals with Approach B	2.30E+05	2.04E+04	1.56E+05	1.96E+04	2.20E+03	1.08E+05	
TOTAL FOR MASS BAYS WITH APPROACH A =					4.19E+05		
TOTAL FOR MASS BAYS WITH APPROACH B =					5.36E+05		

Figure 49. Zinc load to Mass Bay by source (kg/yr).



Estimates include all point/nonpoint
Groundwater was not estimated.

Figure 50. Relative contributions to zinc load.



Mercury

Loadings of mercury are provided in Table 105 and Figures 48 and 49. Because so few data were available for mercury, we calculated loading using only Method A.

Our calculations indicate that NPDES discharges account for about one half the mercury entering the system. There were no data for mercury concentrations in NPDES discharges, except for values that were below detection limits for MWRA effluent and sludge. We therefore developed worst-case estimates, based upon the detection limits for effluent and the TSS content of other POTWs discharging into the system. Our estimates of total mercury entering the system from point sources, 231 and 257 kg/yr, are almost certainly high.

Runoff accounts for 27% of our estimate of mercury loading. This estimate was based entirely upon data from the NCPDI.

Estimates of inputs from the atmosphere ranged from 24 to 73 kg/yr. However, there are no data on the concentration of mercury in the region, the deposition velocity of mercury, or its washout ratio. Therefore, these values are very uncertain.

Table 105. Mercury load to Mass Bay by source (kg/yr).

	Drainage Area						
Source	Merrimack	North Shore	Boston Harbor	South Shore	Cape Cod	Direct	Totals
Drainage Area Calculation Using Method A							
NPDES	3.64E+00	2.73E+01	2.26E+02	5.06E-01			2.57E+02
Runoff/CSOs	2.88E+01	3.00E+01	8.62E+01	3.75E+00	1.09E+00		1.49E+02
Groundwater							0.00E+00
Totals =	3.24E+01	5.73E+01	3.12E+02	4.26E+00	1.09E+00	0.00E+00	4.06E+02
Drainage Area Calculation Using Method B							
Coastal NPDES							0.00E+00
Coastal Runoff/CSOs							0.00E+00
River Discharge							0.00E+00
Groundwater							0.00E+00
Totals =	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Direct Sources to Mass Bays							
Atmosphere						7.30E+01	7.30E+01
Dredged Material						7.88E+01	7.88E+01
Totals with Approach A	3.24E+01	5.73E+01	3.12E+02	4.26E+00	1.09E+00	1.52E+02	
Totals with Approach B	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.52E+02	
TOTAL FOR MASS BAYS WITH APPROACH A =					5.59E+02		
TOTAL FOR MASS BAYS WITH APPROACH B =					NA		

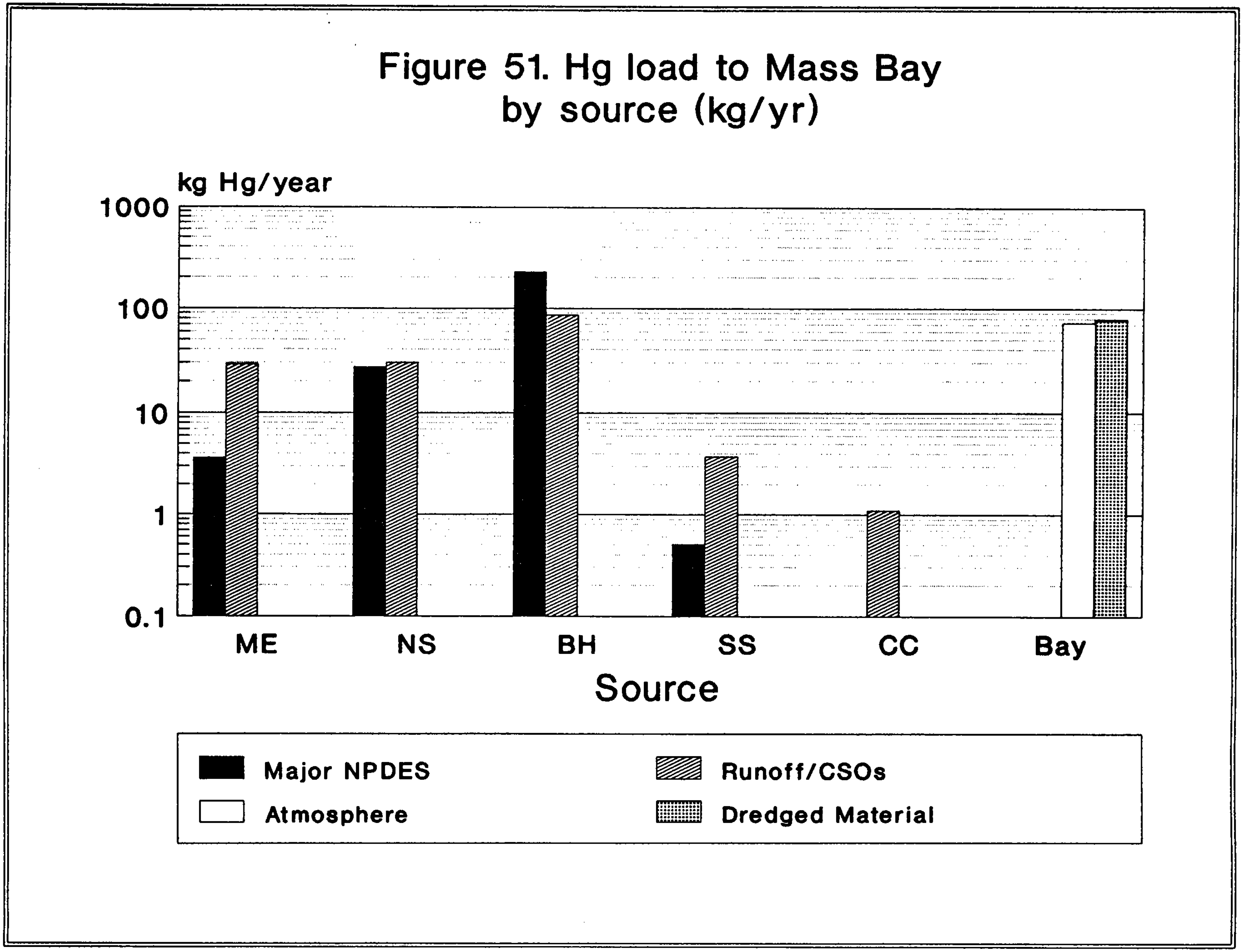
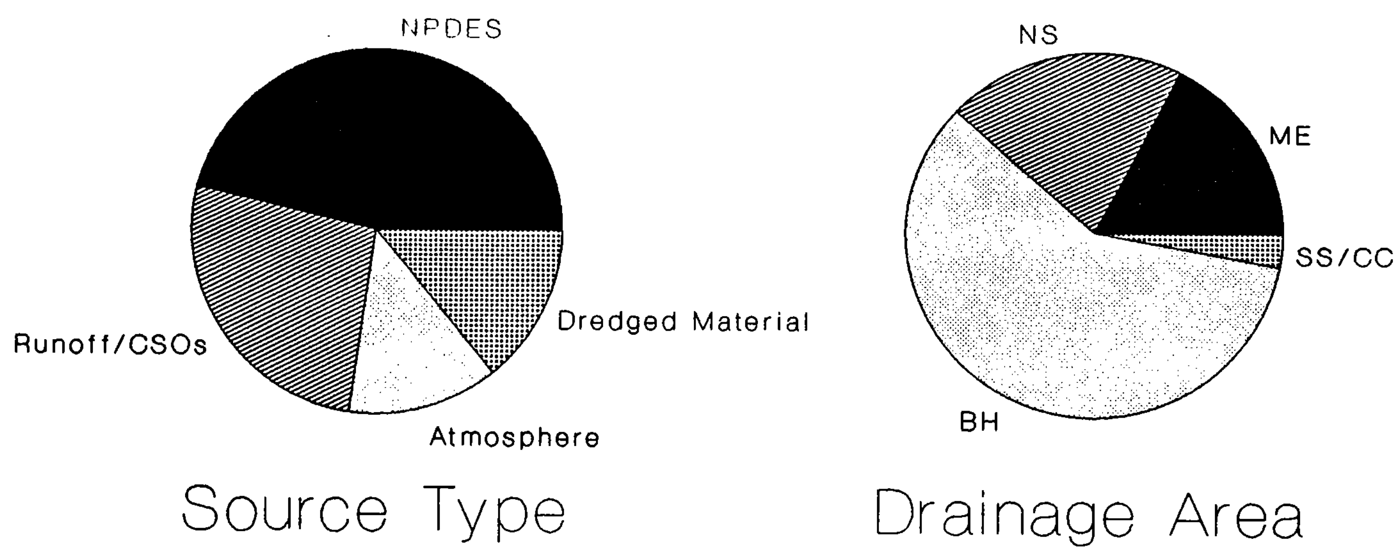


Figure 51. Hg load to Mass Bay
by source (kg/yr)
kg Hg/year
1000
100
10
1
0.1
ME
NS
BH
SS
CC
Bay
Source
Major NPDES
Runoff/CSOs
Atmosphere
Dredged Material

Figure 52. Relative contribution to Hg load.



6.2 Identified Pollutant Problems In Nearshore Waters

The Massachusetts Division of Water Pollution Control (DWPC, 1988) has published information on the environmental conditions of rivers and coastal areas of the state. This information is included in the DWPC (1988) Appendix III - Basin/Segment Information, Commonwealth of Massachusetts Summary of Water Quality for 1988.

The data presented by DWPC was examined as part of this study near the mouths of rivers (within 10 miles) and along the coast for the five drainage areas. This material is presented in Appendix D for 85 locations identified in these areas.

A summary of the DWPC data for the 85 coastal and river mouth locations is provided in Table 106. High coliform bacteria levels was the most common problem identified, with 86% of the areas exhibiting these conditions. Shellfish bed closures were identified as problems for 21% of the areas and low dissolved oxygen was identified as a problem in 19% of the areas.

Sediment contamination by metals and organic compounds was reported as a problem in 21% and 10.6% of the areas respectively. Eutrophication/nutrient problems were identified in 9.4% of the areas.

A broad range of nonpoint and point sources was identified as sources of the problems in coastal areas and within river mouths (Appendix D). In many cases the source of the observed problems was unknown but in others the sources have been identified along with specific abatement needs. In many locations additional studies are recommended.

The information presented in Appendix D underscores the importance of examining local sources of pollutants in assessing pollutant abatement needs. The material also indicates that there are a number of water quality problem areas along the Massachusetts coastline and within the mouths of estuaries and rivers.

Table 106. Identified water quality problems in near-coastal areas.

Drainage Areas	Number of Areas	Low D.O.	High Coliform	Shellfish Beds	Metals in Sediments	Organics in Sediments	Nutrients/ Eutrophication	Oil and Grease	Aesthetics
Merrimack River	2		2	1	1				
North Shore Drainage	25	5	21	2	13	9	3	1	
Boston Harbor Drainage	18	5	15	2	4		3	1	1
South Shore Drainage	19	6	14	6			2		
Cape Code Coastal Drainage Area	21	0	21	12					
Totals	85	16	73	23	18	9	8	2	1
Percent of Areas Evaluated	100.00%	18.82%	85.88%	27.06%	21.18%	10.59%	9.41%	2.35%	1.18%

6.3 Qualifications and Data Gaps

This report provides estimates of loadings from a broad range of sources and at a range of spatial scales. However, several factors must be considered with regard to using the data presented in this report for risk assessment or risk management purposes:

1. There are many uncertainties associated with estimates. These stem from lack of data. In many cases we estimated loadings based on literature values or by extrapolating from similar systems. These estimates provide an overview of the relative magnitudes of sources and provide insights into the potential for discriminating among sources. However, the ranges in estimates are broad and thus, the estimates provided in this report should not be viewed as precise.

2. The fate and effects of chemicals or biological agents in the environment will depend on where and how the materials are introduced to the system. The loadings presented in this report differ in their "delivery systems". For example, atmospheric deposition is spread out over a large area and represents a large but diffuse source. On the other hand, an NPDES discharge is localized, as is the disposal of dredged material. The manner in which chemicals are introduced is especially important with regard to potential receptors. For example, atmospheric deposition will occur directly to the sea surface and may directly affect the sea surface microlayer. Subsurface diffusers from outfalls are typically located on or near the bottom and are initially mixed with seawater or river water upon discharge; groundwater discharges to nearshore regions and may be important sources at near shore local scales. Inasmuch as delivery systems are a critical part of exposure assessment for marine risk assessment, comparisons of magnitudes of sources should not be the sole basis for evaluating the relative importance of the sources.

3. Sources will vary somewhat based on seasonal factors. We identify two kinds of seasonal variability. First, there are sources that vary because of natural periodicity. Examples include river flow, nonpoint source runoff, and groundwater discharge. These vary both seasonally and as a result of storm events. Thus loads associated with these dischargers will be higher during certain times of the year and may be relatively "more important" at those times. Straight comparisons of annual means does not provide a complete picture of the characteristics of these loads. In the case of stormwater runoff, short term events are especially important if there is the potential for short-term acute effects resulting from suspended sediment, nutrient, or chemical loads.

   Second, relatively constant sources such as the major NPDES outfalls will result in short-term and seasonal variability in receiving waters as a result in natural variations in the hydrodynamics of the receiving water. Thus, concentrations of materials discharged from an outfall may be higher in receiving waters during low river flow periods as compared to high flow periods. This "apparent" temporal variability is important in evaluating the loadings from point sources.

Data Gaps

Many data gaps emerged during the course of this study. However, the occurrence of data gaps does not necessarily mean that studies are needed to address them. We suggest that data gaps be addressed as part of the risk assessment. This would involve (1) identifying the those marine resources that represent "receptors" ; (2) identifying the water quality conditions that are thought to pose hazards to the receptors; (3) quantifying the magnitudes of the exposure conditions; (4) assessing risks; and (5) identifying sources that may be contributing to the exposure conditions on a local, regional (drainage basin), or bay-wide basis. Once this framework is in place and an initial effort has been made to assess risks, it should be possible to identify which "data gaps" are most important to address from a risk assessment and management basis.

We have not attempted to generate an exhaustive list of data gaps. However, there are several areas that have emerged which should be considered on a preliminary basis:

- Sources of PAHs to the marine environment - few data were available on PAHs.

- Elevated levels of contaminants in sediments. Although heavily contaminated sediments have been identified in the report, and we have summarized available data, we have not determined how to consider them as sources. Resuspension from the sediments has not been considered in our comparison of relative magnitude of sources of contaminants to the bays.

- Varying spatial scales. We assessed loads from sources that vary in spatial scale. However, we have not determined appropriate how the different spatial scales affect the fate and effects of various contaminants.

- Oil spills. Oil spills and other infrequent, large-scale events were not considered.

- Marine pump-out facilities. We did not consider pump-out facilities or other discharges from marinas.

- Groundwater. Loadings of nitrogen from groundwater appears to be an important source of nutrients to embayments along the shores of Cape Cod. Concentrations of nutrients should be measured within these embayments to verify this source.

- Synthetic organic compounds. Few data are available on pesticides and other synthetic organic compounds, and their loads were not evaluated in this report.